Essays on International Finance and Regulation

by

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Abstract

This dissertation analyzes several questions related to international finance and regulation. The first chapter analyzes the effect of macroprudential policy on economic growth. The second chapter analyzes the effect of market insurance on sovereign borrowing. The third chapter analyzes the role of self-regulation versus government regulation.

The first chapter studies the impact of optimal macroprudential policy on financial stability and economic growth. Many emerging market economies have used macroprudential policy to mitigate the risk of financial crises and the resulting output losses. However, macroprudential policy may reduce economic growth in good times. I introduce endogenous growth into a small open economy model with occasionally binding collateral constraints in order to study the impact of macroprudential policy on financial stability and growth. In a calibrated version of the model, I find that optimal macroprudential policy reduces the probability of crisis by two thirds at the cost of lowering average growth by a small amount (0.01 percentage point). Moreover, macroprudential policy can generate welfare gains equivalent to a 0.06 percent permanent increase in annual consumption.

The second chapter studies the welfare gains from market insurance. It is a joint work with Fabian Valencia. Over the past two decades, Mexico has hedged oil price risk through the purchase of put options. We examine the welfare gains from hedging as a complement to issuing defaultable debt using a standard sovereign default model calibrated to Mexican data. We show that hedging can increase welfare by reducing income volatility and default incentives, which ultimately reduces risk spreads on sovereign debt. We find welfare gains equivalent to a permanent increase in consumption of 0.44 percent. We then decompose these gains by examining whether they come from a reduction in risk spreads or income smoothing. We conclude that about 90 percent of welfare gains stem from the former channel. Sensitivity analyses show that the welfare gains decline when the cost of the options exceeds the actuarially fair price, and increase with the hedged volume of oil, the strike price, the volatility of oil prices, and with introducing risk aversion among foreign investors. Finally, selling oil forward can generate larger welfare gains than buying put options.

The third chapter studies the trade-off between self-regulation and government regulation. Who should be responsible for industry regulation, a private self-regulatory agency or a public agency? This chapter provides a simple framework to analyze the optimal scope of a private self-regulatory organization (SRO) versus government regulation. The trade-off depends on three key elements: externalities, monopoly distortions and the degree of asymmetric information. Self-regulation is more desir-

ABSTRACT

able than government regulation if the degree of asymmetric information between the public regulator and private industry is larger than the size of monopoly distortion and externalities from the industry to society. An optimal mechanism consists of both self-regulation and government regulation where an SRO internalizes externalities within the industry and the government corrects any distortions generated by the SRO. These insights can be applied to many practical settings and policy discussions—for example, in the context of the financial sector, as with the Financial Industry Regulatory Authority (FINRA).

Advisors: Olivier Jeanne, Anton Korinek and Christopher Carroll

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Dedication

This thesis is dedicated to my mom, Ping Fang and my grandma, Xiujie Bai.

Contents

List of Tables

List of Figures

Chapter 1

Financial Stability, Growth and Macroprudential Policy

1.1 Introduction

In the wake of the Global Financial Crisis in 2008-2009, the use of macroprudential policy to manage boom-bust cycles came to the forefront of macroeconomic research. By limiting excessive capital inflows, the goal of macroprudential policy is to mitigate the risk of financial crises and the resulting output losses. However, policy interventions designed to reduce financial instability may negatively affect long-run economic growth.[1] This raises the question of how much impact macroprudential policy has on

[1] Some previous literature suggests that countries with more financial crises have higher average growth rates (see Rancière et al. (2008)). Therefore, macroprudential policy aiming to reduce the frequency of crises may lower average growth.

growth and whether such impact changes the benefits of macroprudential policy.

To answer these questions, this paper introduces endogenous growth into a small open economy (SOE) model with occasionally binding collateral constraints that has been widely used in the literature to make the case for macroprudential policy. Although previous research looks at the welfare consequence of macroprudential policy, financial crises in the existing framework only have a temporary effect on output,[2] which is inconsistent with the data.[3] By introducing endogenous growth, crises in my model have persistent output-level effects, which allows me to analyze the impact of optimal policy on financial stability and economic growth.

In my model, I endogenize growth by introducing an endogenous productivity process, which can be affected by the occasionally binding collateral constraints. In each period, private agents can use resources to invest in a technology that increases productivity. In a crisis, when the collateral constraint binds, they are forced to cut spending and thus investment in the technology. As a result, crisis periods lead to lower growth.

Unsurprisingly, there is room in my model for policy intervention to address overborrowing. Like other papers (e.g., Jeanne and Korinek (2010b) and Bianchi and Mendoza (2018)), I analyze the role of macroprudential policy by considering a social planner with an instrument to manage capital flows.[4] Unlike the existing literature,

[2] In the existing literature, productivity growth is by assumption exogenous. See Jeanne and Korinek (2010b), Bianchi (2011), Benigno et al. (2013), and Bianchi and Mendoza (2018).

[3] There is strong evidence that financial crises have very persistent effects on output. See Cerra and Saxena (2008), Reinhart and Reinhart (2009), Rogoff and Reinhart (2009), and Ball (2014).

[4] This policy is prudential capital control. See Korinek (2011), Jeanne (2012), Jeanne et al. (2012),

however, I do so in an environment that allows me to evaluate the policy's impact on average growth. As an extension, I also analyze the role of a stimulus policy in addition to macroprudential policy by considering a social planner using two instruments to influence the composition of spending. This allows me to evaluate the policy debate on ex-ante and ex-post intervention (see Benigno et al. (2013, 2016) and Jeanne and Korinek (2013)).

In general, the impact of macroprudential policy on average growth is ambiguous. On the one hand, macroprudential policy increases growth during crises because it reduces financial vulnerabilities. On the other hand, it also lowers growth during normal periods because it reduces external borrowing and thus the expenditures to increase productivity. The calibrated version of my model reveals that optimal macroprudential policy reduces the probability of crises from 6.2 percent to 1.9 percent (about two thirds), at the cost of lowering average growth by 0.01 percentage point.

Furthermore, I find that the welfare gains from optimal macroprudential policy are equivalent to a 0.06 percent permanent increase in annual consumption. Similar to existing literature, macroprudential policy increases welfare by limiting the likelihood of financial crises, therefore helping agents to smooth consumption. In fact, in the model, that effect is stronger with endogenous growth. However, macroprudential policy successfully restricts over-borrowing in the upswing, thus reducing average

and IMF (2012) for a detailed overview.

growth. Overall, macroprudential policy still improves welfare. The gains are similar to those in the related literature (see Jeanne and Korinek (2010b) and Bianchi (2011)).

In my model, the use of macroprudential policy limits borrowing and thus spending for the technology for growth. A natural question, then, is to ask whether there are other policy tools that can be implemented in tandem with macroprudential policy (a capital flow tax) to offset the negative impact of the policy on growth. To answer this question, I consider a social planner with two instruments. The first instrument is a capital flow tax, while the second instrument is a growth subsidy that can be used to change the composition of spending on the technology for growth. This exercise also allows me to analyze the role of ex-post intervention because this social planner uses two tools to intervene both ex-ante and ex-post, different from the social planner with only the capital flow tax who only intervenes ex-ante.

I find that the social planner with two instruments can generate much larger welfare benefits than the social planner with only one instrument. Quantitatively, the gains are equivalent to a 0.24 percent permanent increase in annual consumption. Two instruments enable the social planner to intervene ex-post and thus mitigate the cost of crises. These two instruments used ex-post act as a stimulus policy. Ex-ante, the social planner uses capital flow tax to correct over-borrowing in the credit market. In this case, capital flow tax act as a macroprudential policy. However, the social planner also uses the growth subsidy to offset the negative effect of macroprudential policy on growth. The ex-ante growth subsidy thus belongs to the stimulus policy.

The availability of the stimulus policy is beneficial because it leads to a short-run boom in both growth and consumption, which is not seen in the economy with only macroprudential policy.

Relation to Literature

This paper is related to the literature on the relationship between growth and stability, in which empirical evidence often leads to mixed results. There are papers on the cross-country relationship between average growth and volatility of growth. For example, Ramey and Ramey (1995) find a negative relationship between average growth and volatility of growth, while Rancière et al. (2008) argue that countries experiencing more crises (more volatile growth) have higher average growth (see Levine (2005) for a summary). Moreover, there are also papers on the impact of policy on growth and financial stability. For example, Sánchez and Gori (2016) find that certain growth-promoting policies can have negative side-effects on financial stability, while Boar et al. (2017) find that macroprudential policy can increase both financial stability and long-run economic growth. This paper finds a negative relationship between average growth and financial stability for macroprudential policy, consistent with Rancière et al. (2008) and Sánchez and Gori (2016). However, this relationship depends on calibrations and might become positive in some cases, which is consistent with the findings in Ramey and Ramey (1995) and Boar et al. (2017).

This paper is also related to the literature on short-run fluctuations and growth.

There are two existing approaches in the literature to introduce endogenous growth into a standard DSGE framework: One approach models growth following Romer (1990), such as Comin and Gertler (2006), Queraltó (2015), and Guerron-Quintana and Jinnai (2014). The other approach models growth following Aghion and Howitt (1992), such as Ates and Saffie (2016) and Benigno and Fornaro (2017). My way of modeling growth is similar to the first approach, which preserves the representative-agent framework. However, unlike the existing literature, which focuses on a positive analysis, my paper is interested in the characterization of optimal policy and the policy's impact on growth and welfare.

Finally, this paper belongs to the literature on optimal macroprudential policy and capital flow management. The theoretical rationale for macroprudential policy includes pecuniary externalities (see Lorenzoni (2008), Jeanne and Korinek (2010a), and Dávila and Korinek (2017)) and aggregate demand externalities (see Farhi and Werning (2016) and Korinek and Simsek (2016)). The general takeaway from the theories is that ex-ante policy intervention can be welfare-improving, since it addresses over-borrowing in the credit market and thus reduces financial instability. However, the literature has been silent on the effect of ex-ante intervention on economic growth, which is the main focus of this paper. Specifically, this paper introduces endogenous growth into a standard SOE-DSGE model with occasional binding constraints (see Jeanne and Korinek (2010b), Mendoza (2010), and Bianchi (2011)). Unlike in other literature, crises have persistent output-level effects in this model, consistent with the empirical evidence. Furthermore, endogenous growth also enables me to evaluate the debate on ex-ante versus ex-post interventions (see Benigno et al. (2013, 2016) and Jeanne and Korinek (2013)). In particular, I focus not only on the benefits of ex-ante and ex-post interventions but also on their impacts on economic growth.

The organization of this paper is as follows: Section 1.2 presents a benchmark model; Section 1.3 presents a normative analysis for macroprudential policy; Section 1.4 presents the calibration procedure and model performance; Section 1.5 presents quantitative analysis; Section 1.6 presents an extension to analyze the role of other policy instruments; and Section 1.7 concludes.

1.2 Model Economy

This section introduces an analytical framework that incorporates endogenous growth into an SOE model as in Jeanne and Korinek (2010b) and Bianchi and Mendoza (2018). One feature of the model is an occasionally binding collateral constraint. It has been used in the literature since Mendoza (2010) to model financial crises. In the model, normal periods are when the constraint is slack, and crisis periods are when the constraint binds.

1.2.1 Analytical Framework

In my model, the economy is populated by a continuum of identical households that have access to an international capital market and a technology that increases productivity. Due to friction in the financial market, there exist collateral borrowing constraints, and the maximum amount of external borrowing cannot exceed the value of collateral. In normal periods, when the constraints are slack, households are able to finance their desired levels of expenditure through external borrowing. The economy thus grows at a normal rate. In crises, when the collateral constraints bind, households cannot finance enough expenditures for the technology. As a result, the growth rate drops.

Preferences: Households have the following Constant Relative Risk Aversion (CRRA) preferences with the Stone-Geary functional form (see Geary (1950) and Stone (1954)):

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t - \mathcal{H}_t\right) \equiv E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left(c_t - \mathcal{H}_t\right)^{1-\gamma}}{1-\gamma} \tag{1.1}$$

where $\beta \in (0,1)$ is the discount factor, γ is the coefficient of risk aversion, c_t is consumption, and $\mathcal{H}_t$ is the subsistence level of consumption. Given that the economy is growing, I assume that $\mathcal{H}_t$ depends on the level of endogenous productivity z_t and takes the functional form:[5]

$$\mathcal{H}_t = hz_t \tag{1.2}$$

Without $\mathcal{H}_t$, private agents find it costly to cut z_{t+1}, since that implies a permanent future loss in output.[6] As a result, the growth rate barely falls when there is a negative shock. The presence of $\mathcal{H}_t$ reduces the cost of cutting z_{t+1}, since the future subsistence level of consumption $\mathcal{H}_{t+1}$ decreases with z_{t+1}. Therefore, this non-standard assumption with $\mathcal{H}_t$ allows my model to generate a large growth rate decrease in financial crises.[7]

Production Function: Production only requires a productive asset n_t as an input and takes the following form:

$$y_t = A_t n_t^{\alpha} \tag{1.3}$$

where A_t represents the productivity level in the economy and $\alpha \in (0, 1)$. Productive asset n_t is an endowment to households and is normalized to 1. It corresponds to an asset in fixed supply, such as land. In each period, households trade the productive

[5] $h > 0$ is a constant.

[6] As I will explain below, future output y_{t+1} depends on productivity z_{t+1}.

[7] In a model with endogenous growth, it is very costly to reduce productivity, and thus growth, following a shock. Instead, private agents cut consumption spending. To have a large decrease in growth, one may want to raise the cost of cutting consumption, such as by increasing the risk-aversion of utility functions. However, neither a high coefficient of risk aversion γ nor Epstein-Zin preference leads to a large decrease in growth following a crisis. One might also want to introduce habit, as in Campbell and Cochrane (1999). But their formulation introduces an additional state variable, which complicates the computation. My way of modeling $\mathcal{H}_t$ is simpler, and one can interpret it as a habit that depends on the level of z_t in the economy.

asset n_t at a market-determined price q_t.

Endogenous Productivity: The level of productivity A_t takes the following form:

$$A_t = \theta_t z_t \tag{1.4}$$

where θ_t is a stationary exogenous productivity shock, and z_t is non-stationary endogenous productivity chosen by private agents.

Source of Growth: Growth in the economy comes from the endogenous productivity z_t that households can choose. Specifically, there is a technology that costs $\Psi(z_{t+1}, z_t)$ units of consumption to elevate endogenous productivity from z_t to z_{t+1}. I call $\Psi(z_{t+1}, z_t)$ "growth-enhancing expenditures," which include all the expenditures that facilitate long-term economic growth. Here I do not take a stand on any particular form of endogenous growth, but use a generic form that includes many models in the growth literature. For example, $\Psi(z_{t+1}, z_t)$ includes physical capital investment in the AK growth framework as in Romer (1986), human capital investment as in Lucas (1988), R&D expenditure as in Romer (1990) and Aghion and Howitt (1992), etc. The only restriction is that there are no externalities in the process of choosing z_{t+1}. When private agents choose z_{t+1}, they internalize its impact on not only the future subsistence level of consumption $\mathcal{H}_{t+1}$ but also the future cost function, $\Psi(z_{t+2}, z_{t+1})$.

This restriction thus shuts down any externalities in endogenous growth.[8] This departs from the literature on short-run fluctuations and growth, where economic growth is typically suboptimal (see Comin and Gertler (2006) and Kung and Schmid (2015)).

Financial Friction: I introduce a collateral constraint on external borrowing following Jeanne and Korinek (2010b) and Bianchi and Mendoza (2018). Specifically, households can purchase b_{t+1} units of a one-period bond from the international market in each period, and these bonds promise a gross interest rate $1 + r$ in the next period. The domestic economy is atomistic in the international world and takes the interest rate as given. Furthermore, bonds are supplied with infinite elasticity. However, there is a source of financial friction in the market: Private agents need to post their productive assets as collateral for external borrowing, and the maximum amount of external borrowing cannot exceed a fraction $\phi \in (0, 1)$ of the collateral value q_t.[9]

[8] As I will explain in the next section, there are pecuniary externalities in the economy that justify an optimal policy. However, both externalities in growth and pecuniary externalities typically call for policy intervention to increase national saving. If both of them present in the economy, it is hard to disentangle their effects. Furthermore, externalities in endogenous growth tend to dominate pecuniary externalities.

[9] One rationale for the collateral constraint is as follows: There is a moral hazard problem between domestic households and international investors (see Jeanne and Korinek (2010b)). Households have the option to invest in a scam that prevents international investors from seizing future productive assets. This implies that households can default on their debts without any punishment. The investors, however, cannot coordinate to punish the households by excluding them from the market. What they can do is take households to court before the scam is completed. By doing so, they can only seize a fraction ϕ of productive assets and sell them to other households at the prevailing market price q_t. As a result, rational international investors will restrict the amount of external borrowing up to ϕq_t.

Therefore, the collateral constraint can be written as

$$-b_{t+1} \leq \phi q_t \tag{1.5}$$

Budget Constraint: In each period, households make expenditure plans for consumption c_t and growth-enhancing expenditures $\Psi(z_{t+1}, z_t)$ and purchase productive assets $q_t n_{t+1}$ and bond holdings b_{t+1}. Their incomes come from the output y_t, sale of productive assets $q_t n_t$, and existing bond holdings $(1+r)b_t$. As a result, the budget constraint can be written as follows:

$$c_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + b_{t+1} = y_t + q_t n_t + (1+r)\, b_t, \tag{1.6}$$

Market Clearing: There are two markets in the economy: the final goods market and the productive asset market. Given that the productive asset is in fixed supply and owned by the households, the equilibrium condition implies that

$$n_t = 1,\ \forall t \tag{1.7}$$

The final goods market can be pinned down by aggregating the budget constraint for each household and applying the equilibrium condition (1.7) in the productive asset market.

$$c_t + \Psi(z_{t+1}, z_t) + b_{t+1} = y_t + (1+r)\, b_t, \tag{1.8}$$

1.2.2 Competitive Equilibrium (CE)

Competitive Equilibrium: In this economy, equilibrium consists of a stochastic process $\{c_t, z_{t+1}, n_{t+1}, b_{t+1}\}_{t=0}^{\infty}$ chosen by the households and an asset price $\{q_t\}_{t=0}^{\infty}$, given initial values $\{b_0, z_0\}$ and the exogenous shock $\{\theta_t\}_{t=0}^{\infty}$ such that utility (1.1) is maximized, constraints (1.5) and (1.6) are satisfied, and the productive assets and goods market clear, i.e., conditions (1.7) and (1.8) are satisfied.

Recursive Formulation: It is convenient to define net consumption by $c_t^h = c_t - \mathcal{H}_t$ and write the problem in a recursive formulation. State variables at time t include the endogenous variables $\{z_t, n_t, b_t\}$ and the exogenous variable θ_t. I can write the optimization problem as follows:

$$\begin{aligned}
V_t^{CE}(z_t, n_t, b_t, \theta_t) &= \max_{c_t^h, z_{t+1}, n_{t+1}, b_{t+1}} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{CE}(z_{t+1}, n_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \qquad & c_t^h + h z_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + b_{t+1} = \theta_t z_t n_t^{\alpha} + q_t n_t + (1+r) b_t, \\
& -b_{t+1} \leq \phi q_t.
\end{aligned}$$

The maximization problem yields the following optimality conditions for each period:

$$\lambda_t^{CE} = u'\left(c_t^h\right) \tag{1.9}$$

$$\lambda_t^{CE}\Psi_{1,t} = \beta E_t\left[\lambda_{t+1}^{CE}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right] \tag{1.10}$$

$$\lambda_t^{CE} q_t = \beta E_t\left[\lambda_{t+1}^{CE}\left(\alpha\theta_{t+1} z_{t+1} + q_{t+1}\right)\right] \tag{1.11}$$

$$\lambda_t^{CE} = \mu_t^{CE} + \beta(1+r)E_t\left[\lambda_{t+1}^{CE}\right] \tag{1.12}$$

where $\Psi_{1,t} = \frac{\partial\Psi(z_{t+1}, z_t)}{\partial z_{t+1}}$ and $\Psi_{2,t+1} = \frac{\partial\Psi(z_{t+2}, z_{t+1})}{\partial z_{t+1}}$. λ_t^{CE} and μ_t^{CE} are Lagrangian multipliers associated with the budget constraint and collateral constraint, respectively.

Condition (1.9) is the marginal valuation of wealth for households. Condition (1.10) is the key equation for growth in this model, where private agents equate the marginal cost of choosing z_{t+1} with the marginal benefit. The cost is reflected in the partial derivative of the technology function $\Psi_{1,t}$, while the benefit includes a future output θ_{t+1}, excluding the normalized future subsistence level of consumption, h and the partial derivative of future technology function, $\Psi_{2,t+1}$. The marginal cost and marginal benefit are evaluated at the marginal valuation of wealth in periods t and $t+1$ respectively. The third condition (1.11) is a standard asset pricing function, where holding productive asset n_{t+1} yields a dividend income $\alpha\theta_{t+1}z_{t+1}$ and capital gains q_{t+1}. The last condition (1.12) is the Euler equation for holding bonds. The additional term μ_t^{CE} captures the effect of collateral constraint on the external borrowing. When the collateral constraint (1.5) binds, the marginal benefit of borrowing to increase consumption exceeds the expected marginal cost by an amount equal to the shadow price of relaxing collateral constraint μ_t^{CE}.

Normalized Economy: To solve for a stationary equilibrium, I normalize all the endogenous variables by z_t and denote this by variables with hats. Specifically, I denote $\hat{x}_t = \frac{x_t}{z_t}$, where $x_t = \{c_t^h, b_t, q_t, V_t^{CE}, \cdots\}$, and endogenous growth rate $g_{t+1} = \frac{z_{t+1}}{z_t}$. The normalized equilibrium conditions are given in Appendix A.3.

1.3 Optimal Macroprudential Policy

Consistent with the literature, there is a role for macroprudential policy in the economy due to the presence of pecuniary externalities (see Lorenzoni (2008) and Dávila and Korinek (2017)).[10] These pecuniary externalities are related to a vicious cycle associated with the collateral borrowing constraints. Intuitively, private agents need to cut spending when a negative shock hits and the constraints bind. However, asset prices fall with a decline in spending, and private agents need to cut spending further due to lower collateral values and tighter borrowing constraints. Therefore, the initial shock is endogenously amplified through the constraints. Importantly, private agents, taking the asset price as given, fail to internalize their contributions

[10] Pecuniary externalities refer to externalities associated with prices. In an economy with incomplete markets, allocations with pecuniary externalities are generically sub-optimal. For a detailed proof, see early contributions by Geanakoplos and Polemarchakis (1986) and Greenwald and Stiglitz (1986).

to this vicious cycle, which represents pecuniary externalities in the economy. As a result, they over-borrow in normal periods. The optimal macroprudential policy is designed to correct this over-borrowing in the credit market.

Following the literature, I first define the social planner's problem and then choose macroprudential policy to implement the allocation (see Jeanne and Korinek (2010b), Bianchi (2011), and Bianchi and Mendoza (2018)). This is similar to the "primal approach" in optimal policy analysis (originally from Stiglitz (1982)), in which the social planner can choose allocations subject to resource, implementability, and collateral constraints. This formulation allows me to see the wedge between the social planner and private agents in choosing allocations and understand the inefficiencies in the economy. To implement the social planner's allocation, I consider what tax or subsidy with lump-sum transfers is needed to close the wedge. In this case, a tax on capital flows is needed.

Specifically, I consider the social planner who chooses allocations on behalf of the representative household subject to the same constraints as private agents, but who lacks the ability to commit to future policies. Importantly, I assume that the asset price q_t remains market-determined and that the Euler equation of asset price (1.11) enters the social planner's problem as an implementability constraint. The implicit rationale is that the social planner cannot directly intervene with respect to the asset price but internalizes how the allocations affect it and thus the collateral constraint.[11]

[11] I do not allow the social planner to trade assets on behalf of private agents. One rationale is that private agents are better than the planner at observing fundamental payoffs of financial assets

Furthermore, I assume that endogenous productivity z_{t+1} is chosen by private agents and that the Euler equation of productivity (1.10) also enters the social planner's problem as an additional implementability constraint. This is because I use macroprudential policy to decentralize this social planner's allocation and the policy is designed to correct the wedge only in the bond holdings. To correct other wedges, such as that in productivity, an additional instrument is needed. I analyze this case in Section 1.6.

I call the social planner with macroprudential policy a *macroprudential social planner* and denote her allocation with a superscript "MP". As described before, the maximization problem can be written as

$$\begin{aligned}
V_t^{MP}(z_t, b_t, \theta_t) \quad &= \max_{c_t^h, z_{t+1}, b_{t+1}, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{MP}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \qquad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r)b_t, \\
& -b_{t+1} \leq \phi q_t, \\
& u'(c_t^h)q_t = \underbrace{\beta E_t\left[u'(c_{t+1}^h)\left(\alpha\theta_{t+1}z_{t+1} + q_{t+1}\right)\right]}_{G(z_{t+1}, b_{t+1})}, \qquad (1.13) \\
& u'(c_t^h)\Psi_{1,t} = \underbrace{\beta E_t\left[u'(c_{t+1}^h)\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right]}_{I(z_{t+1}, b_{t+1})}. \qquad (1.14)
\end{aligned}$$

where equations (1.13) and (1.14) are two implementation constraints, i.e., the Euler equations of choosing productive assets and productivity. I write implementation constraints as functions of future endogenous state variables z_{t+1} and b_{t+1}, since I

(see Jeanne and Korinek (2010b)).

want to solve for time-consistent policy functions as in Bianchi and Mendoza (2018).

Given the definition of the macroprudential social planner, it is straightforward to define constrained inefficiency as follows:

Definition 1. *Constrained Inefficiency*

The competitive equilibrium displays constrained inefficiency if it differs from the allocation chosen by the macroprudential social planner.

To understand the difference between private agents and the macroprudential social planner, I derive the optimality conditions of MP as follows:

$$\lambda_t^{MP} = u'(c_t^h) - \xi_t^{MP} u''(c_t^h) q_t - \nu_t^{MP} u''(c_t^h)\Psi_{1,t} \tag{1.15}$$

$$\lambda_t^{MP}\Psi_{1,t} - \xi_t^{MP} G_{1,t} - \nu_t^{MP}\left[I_{1,t} - u'(c_t^h)\Psi_{11,t}\right]$$

$$= \beta E_t\left[\lambda_{t+1}^{MP}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right) - \nu_{t+1}^{MP} u'(c_{t+1}^h)\Psi_{12,t+1}\right] \tag{1.16}$$

$$\phi\mu_t^{MP} = \xi_t^{MP} u'(c_t^h) \tag{1.17}$$

$$\lambda_t^{MP} = \mu_t^{MP} + \xi_t^{MP} G_{2,t} + \nu_t^{MP} I_{2,t} + \beta(1+r)E_t\left[\lambda_{t+1}^{MP}\right] \tag{1.18}$$

where $\Psi_{11,t} = \frac{\partial^2\Psi(z_{t+1},z_t)}{\partial z_{t+1}^2}$, $\Psi_{12,t+1} = \frac{\partial^2\Psi(z_{t+2},z_{t+1})}{\partial z_{t+2}\partial z_{t+1}}$, $G_{1,t} = \frac{\partial G(z_{t+1},b_{t+1})}{\partial z_{t+1}}$, $G_{2,t} = \frac{\partial G(z_{t+1},b_{t+1})}{\partial b_{t+1}}$, $I_{1,t} = \frac{\partial I(z_{t+1},b_{t+1})}{\partial z_{t+1}}$, and $I_{2,t} = \frac{\partial I(z_{t+1},b_{t+1})}{\partial b_{t+1}}$. λ_t^{MP}, μ_t^{MP}, ξ_t^{MP}, and ν_t^{MP} are Lagrangian multipliers associated with the budget constraint, collateral constraint, and two implementation constraints, respectively.

Wedge in Marginal Valuation of Wealth: The main difference between CE and

MP is reflected in the marginal valuation of wealth, λ_t^{CE} and λ_t^{MP}. One can see that the wedge includes two terms due to the presence of implementation constraints: The first term is $-\xi_t^{MP} u''(c_t^h) q_t$, which captures pecuniary externalities in the economy, and the second term is $-\nu_t^{MP} u''(c_t^h)\Psi_{1,t}$, which captures the inability of the social planner to change z_{t+1}. Consistent with results in the literature, the first term is positive due to condition (1.17). Uniquely, I also have the second term with ν_t^{MP}, which is the shadow price of implementation constraint (1.14). The value of ν_t^{MP} is given by the optimality condition (1.16). Quantitatively, it is small. Hence, the wedge $-\xi_t^{MP} u''(c_t^h) q_t - \nu_t^{MP} u''(c_t^h)\Psi_{1,t}$ is positive.

Due to this wedge, the competitive equilibrium is constrained inefficient, and the social planner chooses a different allocation than do private agents. However, the difference appears only when the constraint is slack. The reason is that the social planner cannot change the allocation when the constraint binds. In the period when the collateral constraint is slack, i.e., $\mu_t^{MP} = 0$, the social planner chooses a higher level of bond holding than do private agents due to a higher valuation of future wealth $E_t\left[\lambda_{t+1}^{MP}\right]$ (see the optimality conditions of bond holding in CE and MP, (1.12) and (1.18)).[12] Hence, there is an over-borrowing issue in competitive equilibrium, consistent with the literature.

Implementation: I assume that the planner has access to a macroprudential tax

[12] Quantitatively, the term $\nu_t^{MP} u''(c_t^h)\Psi_{1,t} + \nu_t^{MP} I_{2,t}$ is small.

$\tau_t^{MP,b}$ on capital flows and a lump-sum transfer T_t^{MP}. The budget constraint for private agents becomes

$$c_t^h + hz_t + \Psi(z_{t+1}, z_t) + q_t n_{t+1} + \left(1 - \tau_t^{MP,b}\right) b_{t+1} = y_t + q_t n_t + (1+r)\, b_t + T_t^{MP}$$

where $T_t^{MP} = -\tau_t^{MP,b} b_{t+1}$.

Proposition 1. *Decentralization with Macroprudential Policy*

The macroprudential social planner's allocation can be implemented by a macroprudential tax $\tau_t^{MP,b}$ on capital flows that is rebated to private agents with a lump-sum transfer T_t^{MP}. Furthermore, the tax $\tau_t^{MP,b}$ is given by

$$\begin{aligned}\tau_t^{MP,b} \quad = \quad & \frac{\beta g_{t+1}^{-\gamma}(1+r)\, E_t\left[\gamma\phi\hat{\mu}_{t+1}^{MP}\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1} + \gamma\hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma-1}\Psi_{1,t+1}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}} \\ & -\frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t\left(\hat{c}_t^h\right)^{-1} + \gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t} - \phi\hat{\mu}_t^{MP} g_{t+1}^{-\gamma}\hat{G}_{2,t}\left(\hat{c}_t^h\right)^{\gamma} - \hat{\nu}_t^{MP} g_{t+1}^{-1-\gamma}\hat{I}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}\end{aligned}$$

Proof. See Appendix A.4.1.

Consistent with the literature, a macroprudential tax $\tau_t^{MP,b}$ is used to correct the wedge between λ_t^{MP} and λ_t^{CE}. It is positive in the quantitative exercise, since the Lagrangian multiplier ν_t^{MP} is small. Hence macroprudential policy is also used to correct the over-borrowing issue in the economy.

1.4 Calibration

This section first describes an 11-year event window that the model targets. It then shows parameter values and the model's ability to fit the data.

1.4.1 Targeted Event Window

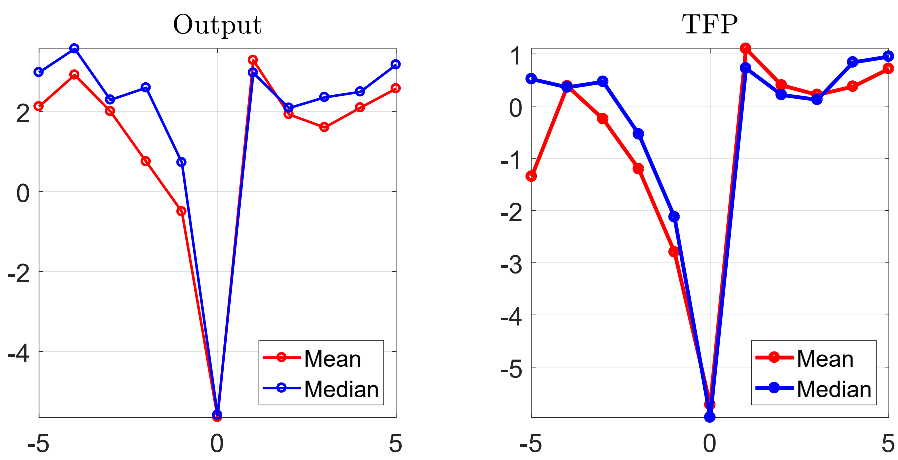
One key feature of the model is its generation of such persistent output-level effects of financial crises as found in the data (see Cerra and Saxena (2008), Rogoff and Reinhart (2009), and Ball (2014)). To quantify the magnitude of output cost for later calibration, I construct an 11-year event window of output growth rates centering on one specific type of financial crisis in emerging markets, i.e., sudden stop episodes.[13] These episodes occur when there is a sudden slowdown in private capital inflows to emerging market economies and a corresponding sharp reversal in current account balances. For the identification of sudden stops, I use the episodes in Calvo et al. (2006) ("Calvo episodes"), whose criterion is based on a sharp reversal in current account balances and a spike in spreads. For robustness, I also use episodes identified in Korinek and Mendoza (2014) ("KM episodes") and report the results in Appendix A.2.

The left panel of Figure 1.1 shows that the growth rate of real GDP per capita is a stationary process and falls to −5.65 percent at the time of crises. I also construct an event window for "Total Factor Productivity (TFP)" in the right panel of Figure

[13] The source of real GDP per capita is explained in Appendix A.1.

1.1 and find that productivity displays a similar pattern to output, consistent with the predictions of my model.

Figure 1.1: Growth Rates in Sudden Stop Episodes (%)



Note: The series are constructed using an 11-year window centering on the sudden stop episodes.

1.4.2 Parameter Values

I calibrate the model to annual frequency using 55 countries' data from between 1961 and 2015 (see Appendix A.1 for details). The model can be solved using a variant of the endogenous gridpoint method, as in Carroll (2006) (see Appendix A.6 for details). There is only one shock in the economy: the exogenous technology shock θ_t, which follows the process below. I discretize the process using Rouwenhorst method as in Kopecky and Suen (2010).

$$\log\theta_t = \rho\log\theta_{t-1} + \varepsilon_t, \text{ where } \varepsilon_t \sim N(0,\sigma^2)$$

where ρ and σ are persistence and volatility of the shock, and ε_t is a random variable following a normal distribution.

It is important to have the shock θ_t in the model to capture the fall of output growth during crises, as seen in Figure 1.1. Without a fall in θ_t, one cannot explain the negative output growth rate in crises, since output y_t depends on the predetermined productivity z_t and the exogenous productivity θ_t.[14] Furthermore, the endogenous response of productivity z_{t+1} prevents the output growth rate after crises from being higher than its long-run average, consistent with the event window.[15]

Assumption 1. *Cost function $\Psi(z_{t+1}, z_t)$ is quadratic and takes the following form:*

$$\Psi(z_{t+1}, z_t) = \left[\left(\frac{z_{t+1}}{z_t} - \psi\right) + \kappa\left(\frac{z_{t+1}}{z_t} - \psi\right)^2\right] z_t,$$

where $\psi > 0$ and $\frac{z_{t+1}}{z_t} \geq \psi$.

I impose a simple quadratic form on $\Psi(z_{t+1}, z_t)$ so as to calibrate my model.

[14] Admittedly, other shocks, such as financial shocks and interest rate shocks, are important for understanding financial crises. However, these shocks alone cannot lead to a drop of output growth in crises in the model, since the productivity z_t is predetermined.

[15] One could also have an exogenous trend shock, as in Aguiar and Gopinath (2007). Introducing an exogenous trend shock, however, does not allow me to analyze the policy's impact on growth.

Given that this way of modeling growth is generic, I calibrate the parameter values in the function by reference to some moments in the data. For example, κ is a scale parameter and is used to match the average share of consumption in GDP. The parameter ψ is the minimum level of endogenous growth g_{t+1} in the model and is used to match the output growth rate after crises in the targeted event window.

I need to assign values to 10 parameters in the model: $\{\beta, r, \gamma, h, \psi, \kappa, \alpha, \rho, \sigma, \phi\}$. The calibration proceeds in two steps. First, some parameter values are standard in the literature. For example, I choose the interest rate r to be 6 percent and the coefficient of risk aversion parameter γ to be 2. The parameter α equals productive asset income's share of total income, and I choose 0.2 following Jeanne and Korinek (2010b). Second, given these parameter values, I jointly choose the remaining parameters to match relevant moments in the data and the targeted event window in Figure 1.1.

Specifically, I use the following parameters to match data moments. Parameter β determines the incentive to borrow and is chosen to match the long-run Net Foreign Asset (NFA) to GDP ratio (-30 percent). Parameter ρ is chosen to match the correlation between the current account and output at -0.25, since I focus on the relationship between capital flows and output growth.[16] Parameter ϕ determines the maximum value of borrowing in the economy and thus the probability of crises.[17] In

[16] Aguiar and Gopinath (2007) find that the persistence of shocks governs the correlation between the current account and output. The correlation is constructed by first de-trending the output series with a HP filter and then calculating the correlation between the current account to GDP ratio and the cyclical component of output.

[17] I calibrate the model such that the collateral constraint marginally binds in the long run and

the model, I define crisis episodes as periods when constraints bind and the magnitude of current account reversal exceeds 1 standard deviation of its long-run average (see Bianchi (2011)). The parameter ϕ is chosen to match the probability of crises at 5.5 percent, a standard value in the literature (see Bianchi (2011) and Eichengreen et al. (2008)). Furthermore, parameters h and κ are jointly chosen to match the average growth rate, 2.3 percent, and the share of consumption in GDP, 77.6 percent. Specifically, h and κ have to satisfy the normalized resource constraint (1.8) and the Euler equation of z_{t+1} (1.10) as follows:

$$\underbrace{\hat{c}_{ss}}_{77.6\%} + \hat{\Psi}(\underbrace{g_{ss}}_{1+2.3\%}) = 1 + \frac{1+r-g_{ss}}{g_{ss}} \underbrace{\hat{b}_{ss} g_{ss}}_{-30\%}$$
$$\Psi_1(g_{ss}) = \beta g_{ss}^{-\gamma}(1 - h - \Psi_2(g_{ss}))$$

where the average value of θ_t is normalized at 1, and the value of h and κ depend on the value of β and ψ.[18]

As explained before, I also want to match the event window in Figure 1.1. The volatility σ governs the minimum level of the exogenous shock θ_t and thus the decline in the output growth rate during crises. Parameter ψ determines the minimum level

the following relationship holds in the steady states:

$$\underbrace{-\hat{b} g_{ss}}_{30\%} = \phi \hat{q}$$
$$\hat{q} = \frac{\beta g_{ss}^{1-\gamma}}{1 - \beta g_{ss}^{1-\gamma}} \alpha$$

[18]Here, I calibrate the economy so that in the long run it is unconstrained and the collateral constraint marginally binds.

of the endogenous growth rate g_{t+1} and thus the decline in the output growth rate one year after crises. Therefore, I choose σ and ψ to jointly match the output growth rate during crises (-5.65 percent) and one period after crises (3.28 percent) in the event window.

In sum, given values of $\{r, \gamma, \alpha, \eta\}$, I pick values of $\{\beta, \psi, \rho, \sigma\}$, which determine values of $\{\phi, \kappa, h\}$. I then simulate the model, calculate moments of the simulated data, construct an event window as in Figure 1.1, and then compare the simulation results with the actual data moments and the targeted event window.[19] The values of all parameters are reported in Table 1.1.

Table 1.1: Calibration

	Value	Source/target
Parameter in production function	$\alpha = 0.2$	Jeanne and Korinek (2010b)
Risk-free interest rate	$r = 6\%$	Benigno et al. (2013)
Risk aversion	$\gamma = 2$	Standard in the literature
Volatility of technology shock	$\sigma = 0.04$	Output growth rate at time of crises = -5.65 %
Parameter in Ψ functions	$\psi = 0.95$	Output growth rate one year after crises = 3.28%
Parameter in Ψ functions	$\kappa = 26.29$	Consumption-GDP ratio = 77.6%
Subsistence level parameter	$h = 0.51$	Average GDP growth = 2.3%
Discount rate	$\beta = 0.968$	Probability of crisis = 5.5%
Persistence of technology shock	$\rho = 0.83$	Correlation between current account and output = -0.25
Collateral constraint parameter	$\phi = 0.0852$	NFA-GDP ratio = -30%

[19] In particular, I simulate the model for 11,000 periods and throw away the first 1000 periods. Data moments are calculated based on the remaining 10,000 periods of simulated data. Furthermore, I identify crisis episodes in the simulated data and calculate the average output growth rate during crises and one period after crises.

1.4.3 Model Performance

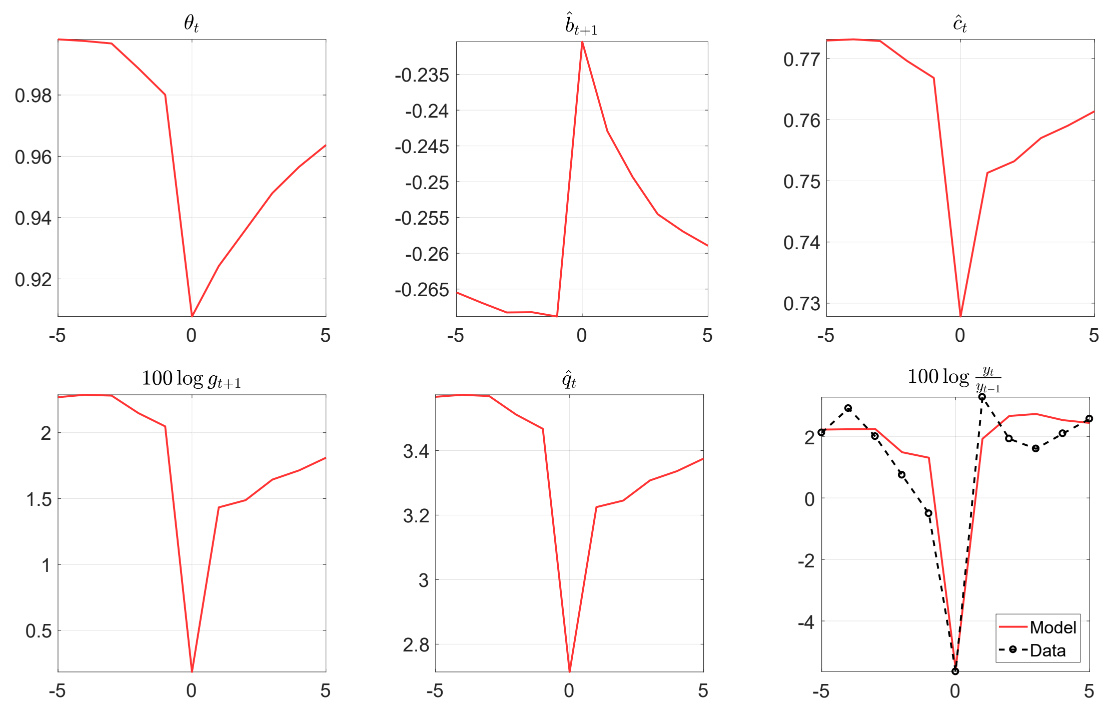
Table 1.2 reports model and data moments. One can see that the model is able to match targeted moments in the data. As other models with occasionally binding collateral constraints, crisis episodes are rare events in my model and occur with a probability of 6.2 percent in the simulation.

Table 1.2: Moments: Data and Model

Targeted Moments	Data	Model
Average GDP growth (%)	2.30	2.31
Probability of crisis (%)	5.50	6.23
NFA-GDP ratio (%)	−30.00	−27.18
Consumption-GDP ratio (%)	77.6	77.53
Correlation between current account and output	−0.25	−0.22

Unlike existing models in the literature, my model can generate the growth rate dynamics in Figure 1.1. To see this, I simulate the model, identify crisis episodes and construct an 11-period event window for different variables in Figure 1.2. Not surprisingly, crises occur when there is a large drop in the exogenous shock θ_t. The current account experiences a large reversal because the borrowing constraints bind and private agents have to cut their external borrowing, i.e., an increase in $\hat{b}_{t+1}$. Furthermore, these events are accompanied by a decline in spending such as consumption $\hat{c}_t$ and growth-enhancing expenditures (reflected in a decline in the endogenous growth rate g_{t+1}). The asset price $\hat{q}_t$ also drops, which leads to an amplification effect through collateral constraints. Fortunately, my model captures the empirical regularity of crises. Importantly, it can capture the persistent output-level effects of crises as in the data: Output growth rates fall during crises with a decline in θ_t and only go back to the long-run average level after crises. This occurs because the endogenous growth rate g_{t+1} decreases during crises.

Figure 1.2: Event Window: Model and Data



1.5 Quantitative Results

In this section, I first compare the allocations of private agents and of the macroprudential social planner, and then analyze policy impacts on average growth. I also calculate welfare gains from macroprudential policy and compare these values with the literature. Lastly, I analyze the size of macroprudential taxes. In Appendix A.5, I conduct a sensitivity analysis with respect to the results.

1.5.1 Comparing CE and MP Allocations

The difference between the macroprudential social planner and private agents is captured by policy functions. Figure 1.3 plots consumption $\hat{c}_t^h$, endogenous growth rate g_{t+1}, asset price $\hat{q}_t$, and bond holding $\hat{b}_{t+1}$ for the competitive equilibrium (red solid line) and the macroprudential social planner (green dashed line) over the bond holding $\hat{b}_t$ when θ_t is 2 standard deviations below its long-run average.[20]

There are kinks in all policy functions due to the presence of the collateral constraint. When the economy starts from a lower bond holding $\hat{b}_t$ (a higher debt to repay), the collateral constraint binds, and private agents have to cut external borrowing and total spending. As a result, both consumption and growth are reduced.

Consistent with the literature, there is an over-borrowing phenomenon in the competitive equilibrium because the social planner chooses a higher bond holding $\hat{b}_{t+1}$ than do private agents. Unlike in the literature, the over-borrowing also has an implication for the endogenous growth rate: The social planner chooses a lower g_{t+1}

[20] I choose θ_t to be at 2 standard deviations below its long-run average because the economy in competitive equilibrium converges to a marginally unconstrained steady state in the absence of future shocks in θ_t. Hence, any small shock to θ_t pushes the economy into a constrained state, i.e., a crisis episode.

when the constraint is slack.

Figure 1.4 displays the ergodic distributions of bond holding $\hat{b}_{t+1}$ and endogenous growth rate g_{t+1}. Compared with private agents, the macroprudential social planner borrows less and thus chooses more mass in the range of higher bond holdings. In terms of the ergodic distribution for g_{t+1}, the social planner has less mass at both extremely low and normal (around 2 percent) growth levels. One can see that the dispersion of growth for MP has been marginally reduced. However, it is unclear whether average growth has been increased or decreased.

To see the impact of macroprudential policy on average growth and the probability of crisis, Table 1.3 reports model moments for the social planner and private agents. With macroprudential policy, external borrowing is reduced from 27.18 percent to 25.78 percent, which lowers average growth from 2.315 percent to 2.307 percent. However, the policy also reduces the probability of crisis from 6.23 percent to 1.89 percent. Hence, the economy becomes more resilient.

Table 1.3: Moments: CE and MP

Moments	CE	MP
Average GDP growth (%)	2.315	2.307
Probability of crisis (%)	6.23	1.89
NFA-GDP ratio (%)	−27.18	−25.78
Consumption-GDP ratio (%)	77.53	77.65
Correlation between current account and output	−0.22	−0.37

Figure 1.5 reports the event window as before but also plots the dynamics of variables for the social planner given the same exogenous shock θ_t. One can see that

the probability of crisis has been reduced by the social planner in the last panel of Figure 1.5. Furthermore, the planner chooses a higher bond holding in normal periods and thus suffers less when the really big shock hits at time 0. As a result, the social planner cuts consumption and growth-enhancing expenditures less during crises.

However, macroprudential policy also reduces borrowing and thus the endogenous growth in normal periods. To show its impact, Figure 1.6 plots the transition dynamics from competitive equilibrium to the equilibrium chosen by the social planner.[21] On balance, the macroprudential social planner borrows less than private agents, which reduces both consumption and endogenous growth. However, the economy becomes more resilient and has a lower probability of crisis. Therefore, consumption converges to a higher level. But the endogenous growth rate g_{t+1} only converges to a lower level because the economy borrows less in the long run.

1.5.2 Policy Impacts on Average Growth

This model allows for an analysis of policy impacts on average growth. It is clear that macroprudential policy increases the endogenous growth rate g_{t+1} during crises but reduces it in normal periods. Even though the policy lowers the volatility of growth unambiguously, its impacts on average growth are ambiguous in theory.

In the baseline calibration, there is a negative relationship between average growth

[21] The transition dynamics is constructed by first running 1,000 simulations of 1,020 periods for competitive equilibrium and then introducing the social planner from period 1,001.

and financial stability for macroprudential policy. But a more general question is which parameters govern this relationship. To answer this question, I proceed by simplifying the model such that it can almost completely be solved analytically.

Instead of using the existing log AR(1) process for θ_t, I assume that $\theta_t = 1$ for all t, and that it falls to 0.9 in the second period, with a probability $p \in [0, 1]$. Furthermore, the economy is unconstrained in a steady state, and I need to change β such that $\beta(1+r)g_{ss}^{-\gamma} = 1$, where $g_{ss} = 1.023$, as in the baseline calibration. I keep other parameter values the same as before. Hence, crisis occurs in the economy when $\theta_2 = 0.9$ and the collateral constraint binds.

I plot the average growth chosen by the private agents and by the social planner in Figure 1.7.[22] Whether the social planner increases or decreases average growth depends on two parameters: The probability of negative shock p and the tightness of the collateral constraint ϕ. Intuitively, the macroprudential social planner can increase average growth because she reduces the cost of crisis and thus raises the growth rate during a crisis. However, a crisis occurs with probability p, and its cost depends on the tightness of the collateral constraint. When p is higher or ϕ is lower, macroprudential policy is very beneficial, since the expected cost of crisis is relatively large. Hence, the policy can increase average growth in these scenarios.

[22] I run 100-period simulations in two separate states to calculate average growth: $\theta_2 = 0.9$ in state L and $\theta_2 = 1$ in state H. The growth rate for each simulation is calculated as follows:

$$G^i = \left(\Pi_{t=1}^{100} g_{t+1}\right)^{\frac{1}{100}}, \text{ where } i \in \{H, L\}$$

Therefore, average growth is $p * G^L + (1-p) * G^H$.

I also find that the magnitude of the impacts is small (see Figure 1.7 and Table 1.3). This is because there is an optimal rate of growth defined by the technology $\Psi(z_{t+1}, z_t)$. Macroprudential policy does not change this function directly but only changes the marginal valuation of wealth. Furthermore, any changes in the growth rate have non-trivial effects on welfare (see Lucas (1987) and Barlevy (2004)). Hence, if the optimal policy has to affect growth negatively in order to increase financial stability, a planner will tend to choose a policy that changes growth only by a small amount. Otherwise, it is too costly for social welfare.

1.5.3 Welfare Gains

To calculate the welfare gains from macroprudential policy, I define a variable $\Delta^{MP}(\hat{b}_t, \theta_t)$, which compares two utilities and converts their difference into consumption equivalents:

$$\Delta^{MP}(\hat{b}_t, \theta_t) = 100 \left[\left(\frac{\hat{V}^{MP}(\hat{b}_t, \theta_t)}{\hat{V}^{CE}(\hat{b}_t, \theta_t)} \right)^{\frac{1}{1-\gamma}} - 1 \right] \tag{1.19}$$

where $\hat{V}^i(\hat{b}_t, \theta_t)$ is a normalized value function and $i \in \{CE, MP\}$.

$\Delta^{MP}(\hat{b}_t, \theta_t)$ depends on state variables $\{\hat{b}_t, \theta_t\}$, and I plot it in Figure 1.8.[23] Consistent with the literature, it peaks in the region where the magnitude of externalities is at its maximum. It becomes smaller when the economy has a higher amount of bond holding, since the probability of future crisis is lower. It also becomes smaller when the economy has a lower amount of bond holding, i.e. when the constraint binds. The macroprudential social planner chooses the same allocation as the private

[23]Like the policy functions, $\Delta^{MP}(\hat{b}_t, \theta_t)$ is plotted over the bond space $\hat{b}_t$ when the shock θ_t is 2 standard deviations below its long-run average.

agents in these regions. Hence, the welfare gains are small.

To understand the average benefit of macroprudential policy, I also define a variable EV^{MP} as follows:

$$EV^{MP} = E\left[\Delta^{MP}(\hat{b}_t, \theta_t)\right] \tag{1.20}$$

where the expectation is taken using the ergodic distribution of $\hat{b}_t$ and θ_t in competitive equilibrium.

The unconditional welfare gains from the macroprudential social planner EV^{MP} are equivalent to a 0.06 percent permanent increase in annual consumption, the same range as in the literature. Hence, endogenous growth does not fundamentally change the benefit of macroprudential policy.

To understand the reason, I decompose the overall welfare gains into two channels: One is a cyclical component of consumption $\hat{c}_t^h$, a traditional channel as in the literature, and the other is a trend component of consumption, i.e., productivity z_t, a new channel with endogenous growth. Specifically, utilities depend on the net consumption series $\{c_t^h\}_{t=0}^{\infty}$, which in turn is the product of the cyclical component of consumption $\{\hat{c}_t^h\}_{t=0}^{\infty}$ and the trend component of consumption $\{z_t\}_{t=0}^{\infty}$. The difference between endogenous and exogenous growth is whether policies can affect the trend component of consumption. If I find that gains come through the cyclical rather than the trend component of consumption, it is not surprising that endogenous growth does not fundamentally change the benefit of optimal policy.

To accomplish that, I run 1,000 simulations and get both cyclical and trend components of consumption for the competitive equilibrium and the social planner. To control for the trend (cyclical) component of the consumption channel, I multiply the trend (cyclical) component of consumption in competitive equilibrium by the cyclical (trend) component of consumption under the social planner to construct a counter-factual consumption. I then compare the utility of this counter-factual consumption with the utility of consumption in competitive equilibrium. The difference between these two is considered as gains through the cyclical (trend) component of consumption channel.

Table 1.4 reports the results. Indeed, gains through the cyclical component of consumption channel are reinforced by endogenous growth: a 0.40 percent permanent increase in annual consumption, which is much larger than those found in the literature. However, there are welfare losses through the trend component of the consumption channel, since the policy reduces average growth. Even if the magnitude of reduction is small, 0.01 percentage point, the cost in terms of welfare is large, a 0.34 percent permanent decrease in annual consumption. Overall, macroprudential policy is still desirable, but the gains are no larger than those in the models with exogenous growth.

Table 1.4: Source of Welfare Gains (%)

	Overall	Trend Consumption Channel	Cyclical Consumption Channel
MP	0.06	−0.34	0.40

1.5.4 Policy Instruments

Figure 1.9 shows the macroprudential tax on capital flows $\tau_t^{MP,b}$.[24] The tax rate varies from 0 to 5 percent, depending on the state variable $\hat{b}_t$, and I find that it is 1.28 percent on average. As explained before, the macroprudential social planner cannot change the allocation when the constraint binds, and I set the tax rate at zero in these regions. Consistent with the literature, the tax rate peaks in the region where the magnitude of externalities is at its maximum. The tax approaches zero when the economy has sufficient bond holdings $\hat{b}_t$.

1.6 Extension: Other Policy Instruments

In this section, I introduce a social planner who has two instruments. For the sake of comparison, I call her a *multi-instrument social planner* (MI). Unlike the macroprudential social planner, who only has one instrument to influence the level of spending, the multi-instrument social planner can also change the composition of spending. Hence, an additional policy is needed to implement her allocation. As I

[24]As before, I plot it over the bond holding $\hat{b}_t$ when the shock θ_t is 2 standard deviations below its long-run average.

will explain later, this new policy can be interpreted as a stimulus policy.

Like the macroprudential social planner, the multi-instrument social planner chooses allocation on behalf of private agents subject to the resource constraint (1.8) and the collateral constraint (1.5). Differently, she only has the asset equation (1.11) as an implementation constraint, not the growth equation (1.10). Therefore, she can choose z_{t+1} without restrictions. Specifically, her maximization problem can be written as

$$\begin{aligned}
V_t^{MI}(z_t, b_t, \theta_t) &= \max_{c_t^h, z_{t+1}, b_{t+1}, q_t} u\left(c_t^h\right) + \beta E\left[V_{t+1}^{MI}(z_{t+1}, b_{t+1}, \theta_{t+1})\right] \\
\text{s.t.} \qquad & c_t^h + hz_t + \Psi(z_{t+1}, z_t) + b_{t+1} = \theta_t z_t + (1+r)b_t, \\
& -b_{t+1} \leq \phi q_t, \\
& u'(c_t^h)q_t = \underbrace{\beta E_t\left[u'(c_{t+1}^h)\left(\alpha\theta_{t+1}z_{t+1} + q_{t+1}\right)\right]}_{G(z_{t+1}, b_{t+1})}.
\end{aligned}$$

where the last constraint is the Euler equation of choosing a productive asset.

The maximization problem implies the following optimality conditions for each period:

$$\begin{aligned}
\lambda_t^{MI} &= u'(c_t^h) - \xi_t^{MI} u''(c_t^h) q_t \\
\lambda_t^{MI}\Psi_{1,t} &= \xi_t^{MI} G_{1,t} + \beta E_t\left[\lambda_{t+1}^{MI}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right] \qquad (1.21) \\
\phi\mu_t^{MI} &= \xi_t^{MI} u'(c_t^h) \\
\lambda_t^{MI} &= \mu_t^{MI} + \xi_t^{MI} G_{2,t} + \beta(1+r)E_t\left[\lambda_{t+1}^{MI}\right]. \qquad (1.22)
\end{aligned}$$

where λ_t^{MI}, μ_t^{MI}, and ξ_t^{MI} are Lagrangian multipliers associated with the budget constraint, collateral constraint, and implementation constraint, respectively.

Wedge in Marginal Valuation of Wealth: The main difference between CE and MI is reflected in the marginal valuation of wealth, λ_t^{CE} and λ_t^{MI}. Like the macroprudential social planner, the multi-instrument social planner values wealth more than private agents do, due to the term $-\xi_t^{MI} u''(c_t^h) q_t$, capturing pecuniary externalities in the economy. Unlike the macroprudential social planner, she can choose productivity freely, as in equation (1.21), and does not have an additional term in the wedge, as in $\lambda_t^{MP} - \lambda_t^{CE}$.

The wedge in the marginal valuation of wealth also has an implication for external borrowing and growth. Unlike the macroprudential social planner, who is constrained to implement the same allocation as private agents when the constraint binds, the multi-instrument social planner shifts spending from growth-enhancing expenditures to consumption. By doing so, she can increase the asset price and thus relax the collateral constraint. When the collateral constraint is slack, she borrows less, for the same reason as the macroprudential social planner does. However, she also chooses a higher growth rate than do private agents so as to offset the negative effect of decreased borrowing on growth.

Implementation: I assume that the social planner has access to a tax $\tau_t^{MI,b}$ on capital flows, a subsidy $\tau_t^{MI,z}$ on growth-enhancing expenditures, and a lump-sum transfer T_t^{MI}. The budget constraint of private agents becomes

$$c_t^h + hz_t + \left(1 - \tau_t^{MI,z}\right)\Psi(z_{t+1}, z_t) + q_t n_{t+1} + \left(1 - \tau_t^{MI,b}\right) b_{t+1} = y_t + q_t n_t + (1+r)\, b_t + T_t^{MI}$$

where $T_t^{MI} = -\tau_t^{MI,z}\Psi(z_{t+1}, z_t) - \tau_t^{MI,b} b_{t+1}$.

Proposition 2. *Decentralization with Two Instruments*

The multi-instrument social planner's allocation can be implemented by a tax $\tau_t^{MI,b}$ on capital flows and a subsidy $\tau_t^{MI,z}$ on growth-enhancing expenditures, which are rebated to private agents with a lump-sum transfer T_t^{MI}. Furthermore, $\tau_t^{MI,b}$ and $\tau_t^{MI,z}$ are given by

$$\begin{aligned}
\tau_t^{MI,z} &= \frac{\beta g_{t+1}^{-\gamma} E_t \left[\hat{c}_{t+1}^{-\gamma} \tau_{t+1}^{MI,z} \Psi_{2,t+1} + \gamma\phi\hat{\mu}_{t+1}^{MI} \hat{q}_{t+1} \left(\hat{c}_{t+1}^h\right)^{-1} (\theta_{t+1} - h - \Psi_{2,t+1})\right]}{\Psi_{1,t}\left(\hat{c}_t^h\right)^{-\gamma}} \\
&\quad - \frac{\gamma\phi\hat{q}_t \left(\hat{c}_t^h\right)^{-1} \hat{\mu}_t^{MI}\Psi_{1,t} - \phi\hat{\mu}_t^{MI}\left(\hat{c}_t^h\right)^{\gamma} g_{t+1}^{-\gamma}\hat{G}_{1,t}}{\Psi_{1,t}\left(\hat{c}_t^h\right)^{-\gamma}}, \\
\tau_t^{MI,b} &= -\frac{\gamma\phi\hat{q}_t \left(\hat{c}_t^h\right)^{-1} \hat{\mu}_t^{MI} - \phi\hat{\mu}_t^{MI}\left(\hat{c}_t^h\right)^{\gamma} g_{t+1}^{-\gamma}\hat{G}_{2,t} - \beta g_{t+1}^{-\gamma}(1+r) E_t\left[\gamma\phi\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1}\hat{\mu}_{t+1}^{MI}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}}
\end{aligned}$$

Proof. See Appendix A.4.2.

I need two instruments $\left\{\tau_t^{MI,z}, \tau_t^{MI,b}\right\}$ to close the wedge between λ_t^{MI} and λ_t^{CE} on allocations, since it affects two decision margins in the economy. Both instruments are used ex-ante and ex-post. The only instrument I call *macroprudential policy* is the ex-ante capital flow tax $\tau_t^{MI,b}$, the instrument that is available to the macroprudential social planner in the benchmark analysis. When the tax is used ex-post, I call it a *stimulus policy*, a category which also includes the subsidy $\tau_t^{MI,z}$ on growth-enhancing expenditures. Hence, the stimulus policy can be used for both ex-ante and ex-post intervention. The reason that the ex-ante growth subsidy $\tau_t^{MI,z}$ also belongs to the stimulus policy is that the multi-instrument social planner uses it to offset the negative effect of ex-ante capital flows tax $\tau_t^{MI,b}$ on growth.

Discussion on the Two Social Planners: The main difference between the two social planners is the availability of instruments, which is related to the on-going policy debate on ex-ante versus ex-post policy intervention. The macroprudential social planner only intervenes ex-ante, while the multi-instrument social planner intervenes both ex-ante and ex-post. I choose the macroprudential social planner as the benchmark analysis to stay in line with the literature and to focus on the differences between exogenous and endogenous growth.

Furthermore, macroprudential policy is more realistic and relevant for an emerging market to use to smooth boom-bust cycles in capital flows. Empirical results on the effectiveness of macroprudential policy are mostly supportive. For example, Lim et al. (2011) and Bruno et al. (2017) have estimated the effectiveness of macroprudential tools using comprehensive data and argue that such tools are effective in reducing the pro-cyclicality of shocks (see Galati and Moessner (2017) for a summary).[25]

The stimulus policy, however, is hard to implement. In my model, it includes an ex-ante growth subsidy and an ex-post policy intervention. For the ex-post intervention, both capital flow taxes and growth subsidies are used to change the composition of spending in order to raise asset prices and relax the borrowing constraint. Such intervention is required during crises and potentially incurs some cost (see Jeanne and Korinek (2013) and Benigno et al. (2016)). The ex-ante growth subsidy is used to correct pecuniary externalities rather than externalities in endogenous growth, as in the literature. But there exists a fundamental implementation issue because one needs to identify the source of economic growth—i.e., $\Psi(z_t, z_{t+1})$—in order to impose the subsidy. The identification failure typically leads to the futility of a subsidy policy. Indeed, there is little evidence for positive effects of subsidies on productivity (see Westmore (2013)).

1.6.1 Comparing CE, MP, and MI Allocations

Figure 1.10 compares policy functions of CE, MP, and MI. Unlike private agents and the macroprudential social planner, the multi-instrument social planner can shift resources from growth-enhancing expenditures to consumption when the collateral

[25] There are exceptions. For example, Fernández et al. (2015) cast some doubts on the effectiveness of macroprudential policies, since they find the instruments are acyclical, which counters the theoretical predictions for prudential tools. Policies' effectiveness depends crucially on their design. There are issues that might affect their effectiveness. For example, Bengui and Bianchi (2014) investigate the issue of leakage, and Dogra (2014) investigates the issue of private information.

constraint binds. This behavior comes at a second-order cost, since it distorts the first-order conditions of private agents in choosing bond holdings and productivity. However, there is a first-order gain, because it increases the asset price $\hat{q}_t$ and thus relaxes the collateral constraint. As a result, the social planner can borrow *more* even during a crisis, and the crisis is not as costly as in competitive equilibrium; one can see that consumption $\hat{c}_t^h$, endogenous growth g_{t+1}, and asset price $\hat{q}_t$ are much higher. The multi-instrument social planner's allocation in crisis also has implications for her allocation in normal periods: She actually chooses *fewer* bond holdings and a *higher* endogenous growth rate than do private agents, and the constraint becomes binding with a higher level of bond. Hence, the economy ends up with more financial instability.

Figure 1.11 plots the ergodic distributions of bond holdings and endogenous growth rate. Unlike the macroprudential social planner, the multi-instrument social planner chooses more mass in the range of lower bond holdings $\hat{b}_{t+1}$. Like the macroprudential social planner, she also has less mass at both extremely low and normal (around 2 percent) growth levels than at the competitive equilibrium. As a result, the dispersion of growth has been reduced, but the effect on average growth is unclear.

Table 1.5 reports model moments of CE, MP, and MI. From the economy in CE to MI, the probability of crisis has increased from 6.2 percent to 14.2 percent, and average growth is reduced by 0.03 percentage point. This is counter-intuitive but reasonable because the crisis is less costly with the stimulus policy and the social planner strikes a new balance between impatience and precautionary motive. Given that the private agent is impatient, the social planner finds it optimal to borrow *more* and hit the collateral constraint more frequently, since she can intervene ex-post to reduce the cost of crisis. But the ex-post intervention requires a shift of spending from growth-enhancing expenditures to consumption. As a result, average growth rate is even lower in MI than in MP.

Table 1.5: Moments: CE, MP, and MI

Moments	CE	MP	MI
Average GDP growth (%)	2.315	2.307	2.289
Probability of crisis (%)	6.23	1.89	14.23
NFA-GDP ratio (%)	−27.18	−25.78	−28.98
Consumption-GDP ratio (%)	77.53	77.65	77.58
Correlation between current account and output	−0.22	−0.37	−0.54

Even if the multi-instrument social planner lowers average growth, she can still smooth the economy. Figure 1.12 reports the event window as before. One can see that consumption and asset prices fall *less* in MI than in CE and MP during crises. Furthermore, the endogenous growth rate g_{t+1} during crises falls *less* in MI than in CE but *more* than in MP because the social planner shifts resources from growth-enhancing expenditures to consumption. Due to the existence of ex-post intervention, the social planner borrows *more* ex-ante and hits the borrowing constraint more frequently.

Unlike the macroprudential social planner, who increases endogenous growth g_{t+1} during the crisis but reduces it in normal periods, the multi-instrument planner actually increases endogenous growth g_{t+1} in the short run but reduces it in the long run. To demonstrate the difference, I show the transition dynamics in Figure 1.13.

The multi-instrument social planner generates a short-run boom in consumption and growth, since she can intervene ex-post and thus borrows more ex-ante. However, growth converges to a lower level in the long run because resources are used to serve a higher level of external debt. Therefore, the multi-instrument social planner actually faces a trade-off between short and long-run growth. Furthermore, I find that the short-run boom in average growth lasts for 18 years.

1.6.2 Policy Impacts on Average Growth: MI and MP

Given that the multi-instrument social planner has access to the stimulus policy, one natural question is whether she can increase average growth. To answer this question, Figure 1.14 shows average growth in the simplified version of the model, as before. One can see that the social planner indeed increases average growth all the time. The stimulus policy allows the social planner to intervene ex-post, which mitigates the cost of crises. Furthermore, the stimulus policy also offsets the negative effect of macroprudential policy on growth in normal periods. Therefore, average growth is increased for the multi-instrument social planner.[26]

1.6.3 Welfare Gains: MI and MP

Unsurprisingly, the multi-instrument social planner generates larger welfare gains than does the macroprudential social planner thanks to the availability of stimulus policy. Figure 1.15 plots conditional welfare gains. The gains become larger when the constraint binds tighter (a lower bond $\hat{b}_t$), reflecting the importance of stimulus policy.

Average welfare gains are equivalent to a 0.24 percent permanent increase in annual consumption, and the source of the gains is the cyclical component of the consumption channel, as before (see Table 1.6). Furthermore, the gains from this channel do not increase with two instruments. Instead, the welfare loss in the trend component of the consumption channel is significantly reduced, from a 34 percent to a 13 percent permanent decrease in annual consumption. Hence, the stimulus policy reduces the negative impact of macroprudential policy on growth and thus on welfare.

[26] The results are different from our baseline calibration, where average growth for the multi-instrument social planner is decreased. As I explained before, given that the cost of financial crisis is reduced, the social planner finds it optimal to hit the borrowing constraint more frequently. Average growth rate is thus reduced because the resources are shifted from growth-enhancing expenditures towards consumption. However, this channel is not in the simplified version of the model since the probability of crisis is given by the exogenous parameter p.

Table 1.6: Source of Welfare Gains (%): MP and MI

	Overall	Trend Consumption Channel	Cyclical Consumption Channel
MP	0.06	−0.34	0.40
MI	0.24	−0.13	0.38

1.6.4 Policy Instruments

Figure 1.16 plots $\left\{\tau_t^{MI,b}, \tau_t^{MI,z}\right\}$ over the bond space $\hat{b}_t$ when θ_t is 2 standard deviations below its long-run average. For the capital flow tax $\tau_t^{MI,b}$, one can see that it is positive when the constraint is slack (used ex-ante), just as it is for the macroprudential social planner. However, when the initial wealth is low (i.e., $\hat{b}_t$ is low and the constraint binds), the tax becomes negative, meaning that the social planner wants to encourage borrowing. This is because she can relax the constraint in the bad state and thus borrow more than private agents. The growth subsidy $\tau_t^{MI,z}$ is positive in normal periods, since the social planner wants the stimulus policy to offset the negative effect of macroprudential policy on growth. When the constraint binds, it is negative, since the social planner wants to shift resources from growth-enhancing expenditures to consumption so as to relax the borrowing constraint.

Table 1.7 reports the average of capital flows tax and growth subsidy. I find that, on average, capital flow tax is 1.12 percent. The ex-ante tax-macroprudential policy—is 1.1 percent, and the ex-post tax is 1.19 percent. The growth subsidy, on average, is 1.00 percent. The ex-ante subsidy is 1.87 percent, and the ex-post subsidy is −1.78 percent. Based on these results, one might argue that the existence of ex-post intervention reduces the magnitude of ex-ante intervention, as in Jeanne and Korinek (2013). However, this result depends on calibrations (see the sensitivity analysis in Appendix A.5).

Table 1.7: Policy Instruments (%): MP and MI

	Capital Flows Tax	Growth Subsidy
MP	1.28	N.A.
MI	1.12	1.00
MI (Ex-ante)	1.10	1.87
MI (Ex-post)	1.19	-1.78

1.7 Conclusion

This paper introduces endogenous growth into a model with occasionally binding collateral constraints of the type that has been used previously in the literature on macroprudential policy. In the previous literature, binding constraints did not have a long-run impact on output. By contrast, in my model, they do, which increases their cost and presumably might reinforce the case for macroprudential policy. My model thus lends itself to analyzing the role of macroprudential policy in the context of a tradeoff between growth and financial stability.

The impact of macroprudential policy on average growth is, in general, ambiguous. Macroprudential policy reduces the frequency of crises and their impact on growth but comes at the cost of reducing borrowing and growth in good times. To resolve this ambiguity, I look at a calibrated version of the model.

In the quantitative analysis, I find that optimal macroprudential policy substantially reduces the frequency of crisis but has a very small negative effect on average growth. As is known in the literature, changes in average growth have very large welfare impacts (see Lucas (1987) and Barlevy (2004)). Given that optimal macroprudential policy has to lower average growth in order to increase financial stability, it does not change growth by a large amount, because even a small reduction in growth is costly in terms of welfare. Quantitatively, a 0.01 percentage point reduction in average growth leads to a welfare loss equivalent to a 0.34 percent permanent decrease in annual consumption.

Nevertheless, macroprudential policy is still desirable because it reduces the probability of crisis and smooths consumption. The benefits from consumption smoothing actually outweigh the welfare loss from the reduction in average growth. Overall, welfare gains are at the magnitude of a 0.06 percent permanent increase in annual consumption, which is in the same range as in the existing literature.

The model with endogenous growth also allows me to analyze the role of a stimulus policy that is used both ex-ante and ex-post. When such a policy is available, much larger welfare gains can be generated, since the cost of crises is reduced by the ex-post intervention. Ex-ante, macroprudential policy is used to correct over-borrowing in the credit market, and the stimulus policy is used to offset the negative impact of macroprudential policy on growth. Optimal policy thus leads to a short-run boom in growth and consumption, which significantly reduces the welfare loss from a reduction in average growth. In the long run, growth converges to a lower level, since resources are used to serve a higher level of external borrowing. However, the short-run boom in average growth lasts for 18 years.

This paper is suitable fodder for policymakers' reflections about their policies' impacts on average growth and financial stability. One general message is that macroprudential policy only marginally lowers average growth to enhance financial stability. Therefore, it is still desirable to use macroprudential policy, even taking into account its negative impact on average growth. Furthermore, it is always desirable to have a stimulus policy in addition to macroprudential policy, since these two policies complement each other in mitigating the cost of financial crises.

To the best of my knowledge, this is the first paper to analyze the impact of macroprudential policy on growth. Hence, there are many unsolved, interesting questions that I leave for future research. First, my paper is about the role of macroprudential policy in capital flows. However, many countries, including advanced economies, adopted macroprudential policies on other financial markets after the 2008-09 Global Financial Crisis. It would be interesting to look at the effects of other macroprudential policies (leverage ratio, capital requirement, etc). Second, my paper abstracts from the risk-taking behavior in the economy. In the model, macroprudential policy negatively affects growth because it restricts the amount of funding to productive projects. However, private agents might respond to the policy by taking on riskier projects. Such risk-taking behavior might be socially inefficient, even if it is privately optimal.

In the end, excessive risk-taking behavior might lower average growth. Therefore, it may be interesting to see whether average growth is further driven down by optimal policy.

Figure 1.3: Policy Functions: CE and MP

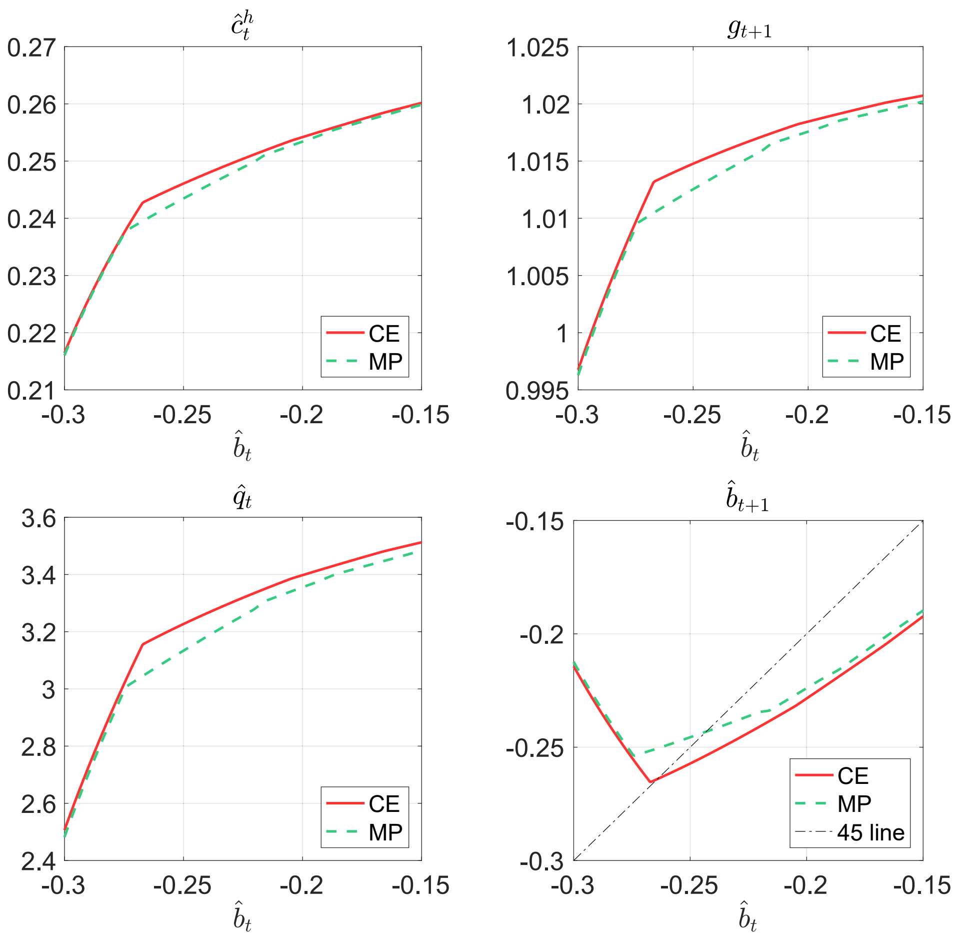


Figure 1.4: Ergodic Distributions: CE and MP

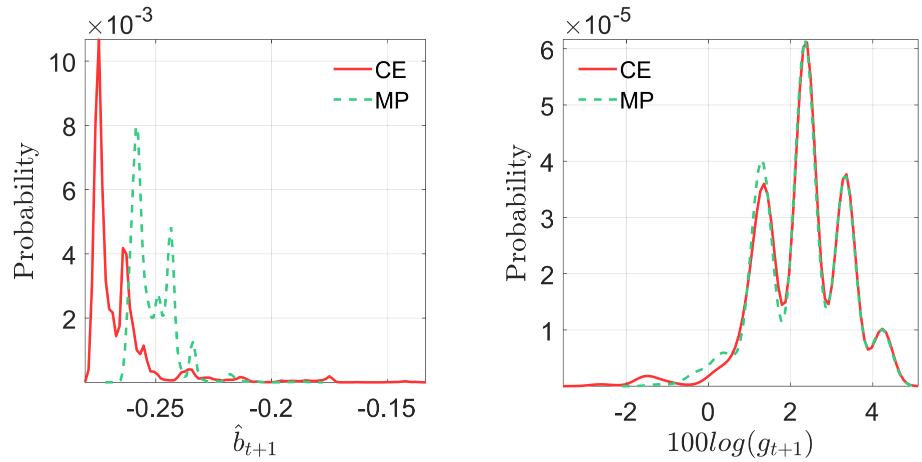


Figure 1.5: Event Window: CE and MP

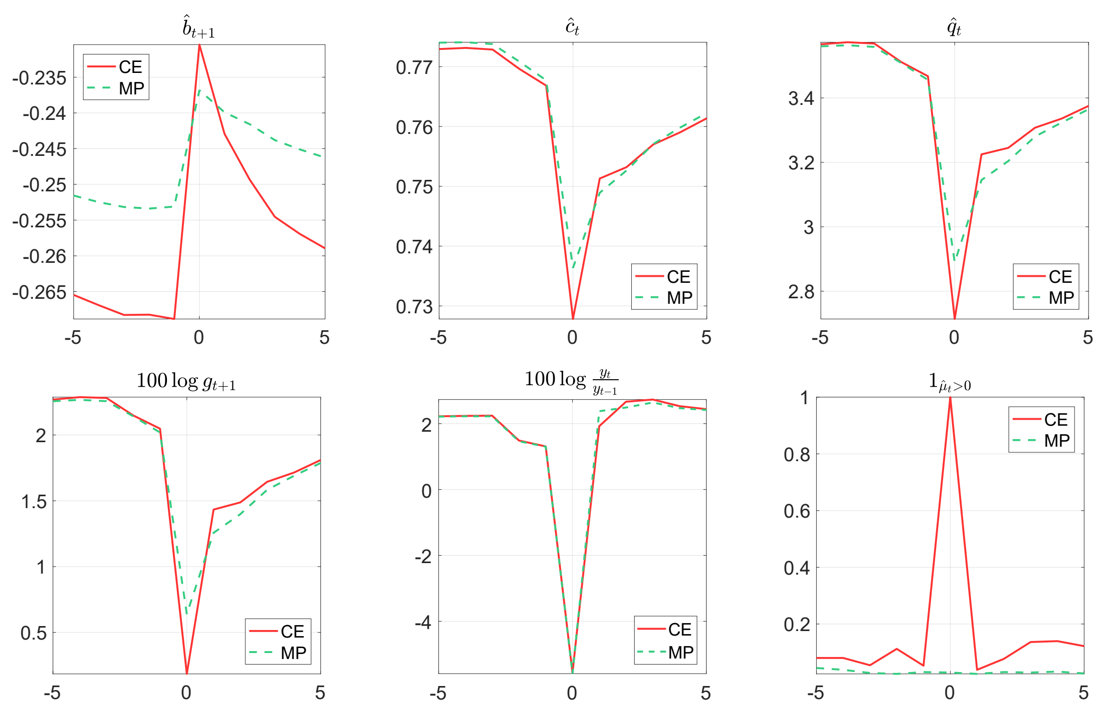


Figure 1.6: Transition Dynamics: CE and MP

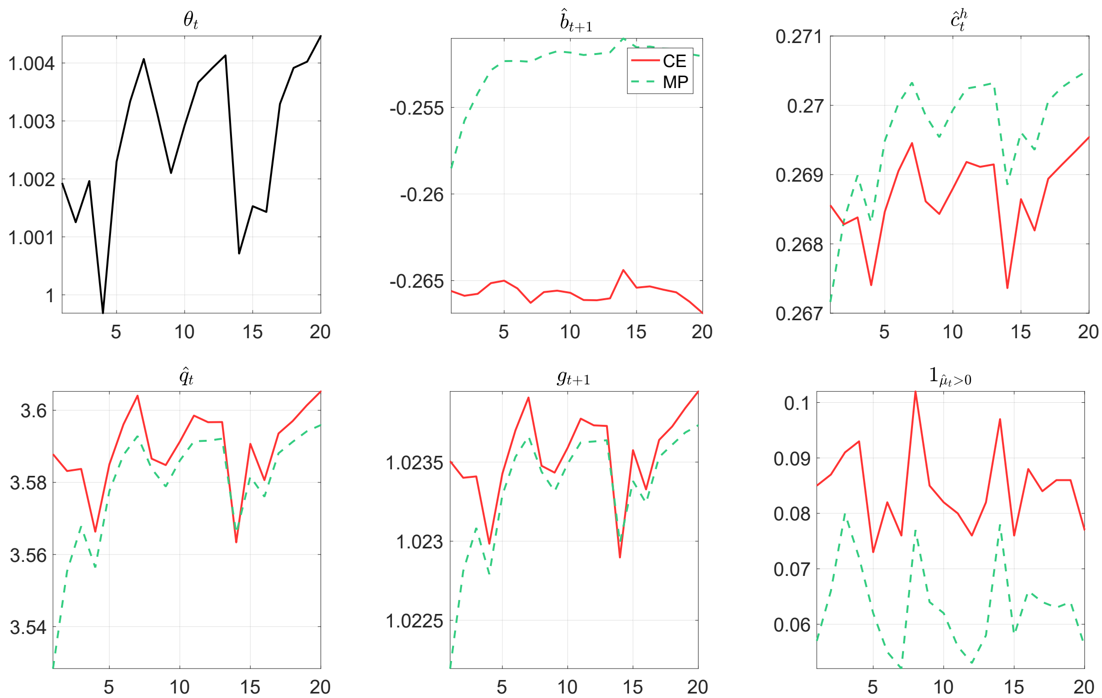


Figure 1.7: Policy Impacts on Average Growth: CE and MP

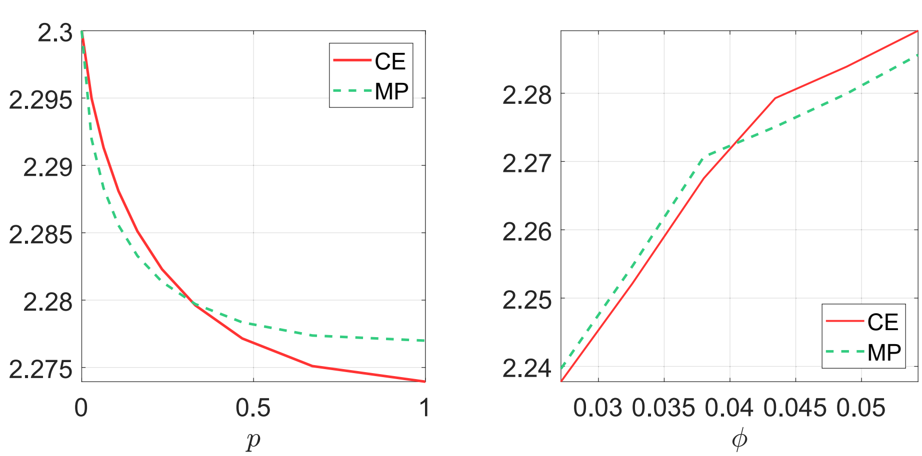


Figure 1.8: Welfare Gains (%): MP

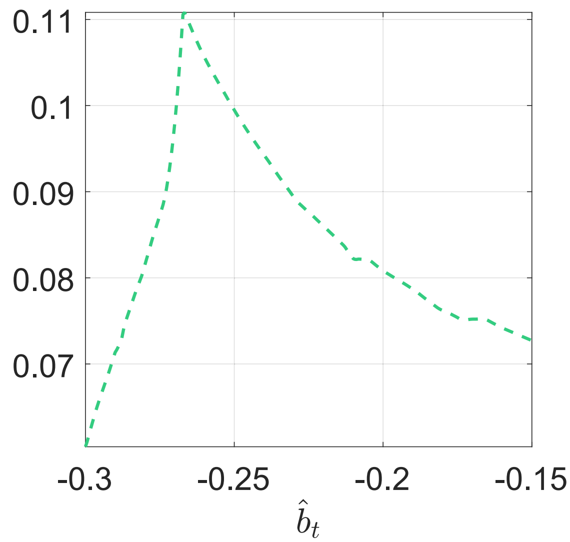


Figure 1.9: Macroprudential Tax on Capital Flows

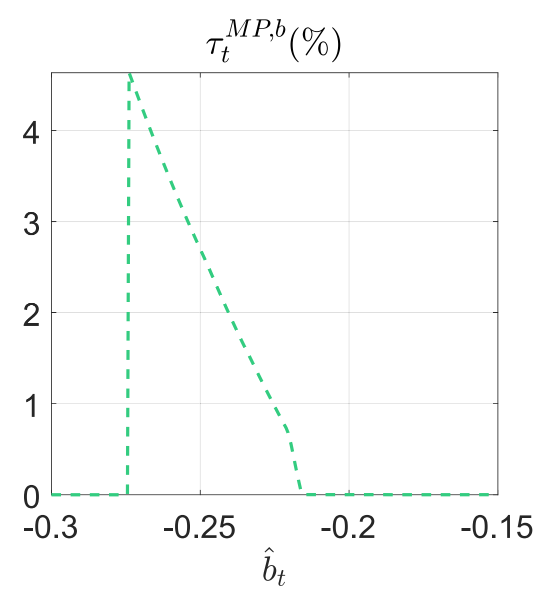


Figure 1.10: Policy Functions: CE, MP and MI

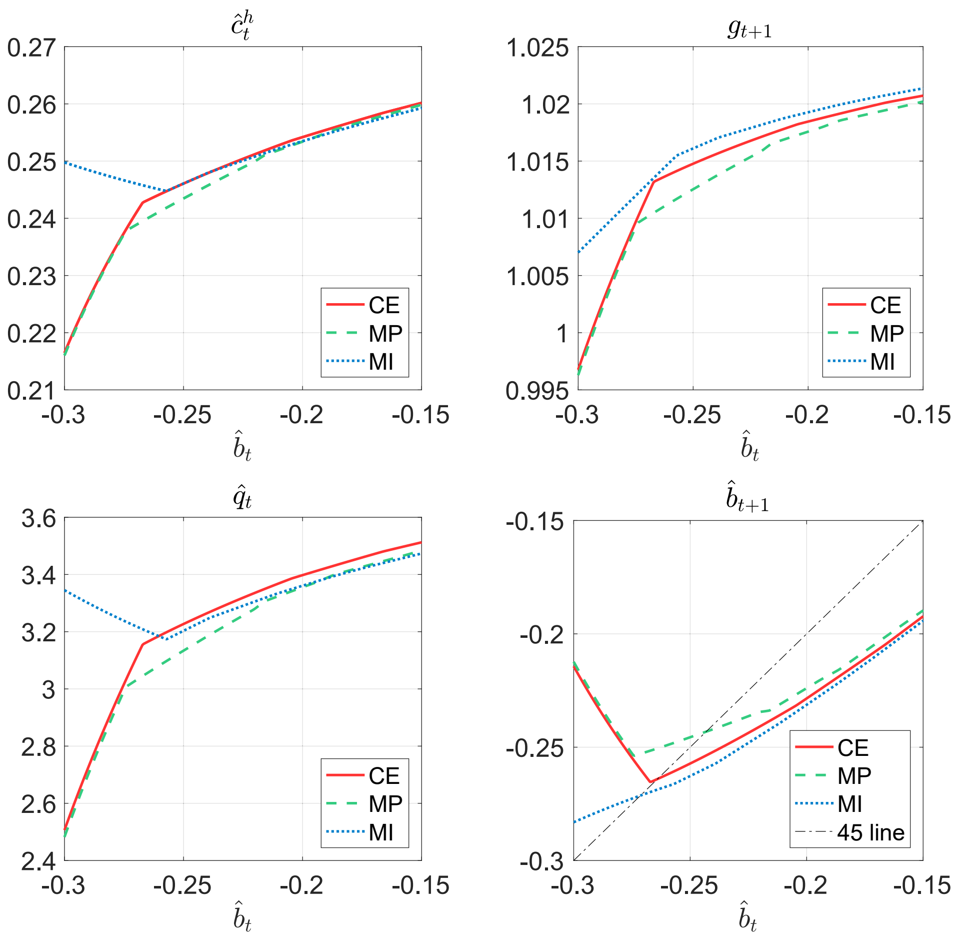


Figure 1.11: Ergodic Distributions: CE, MP and MI

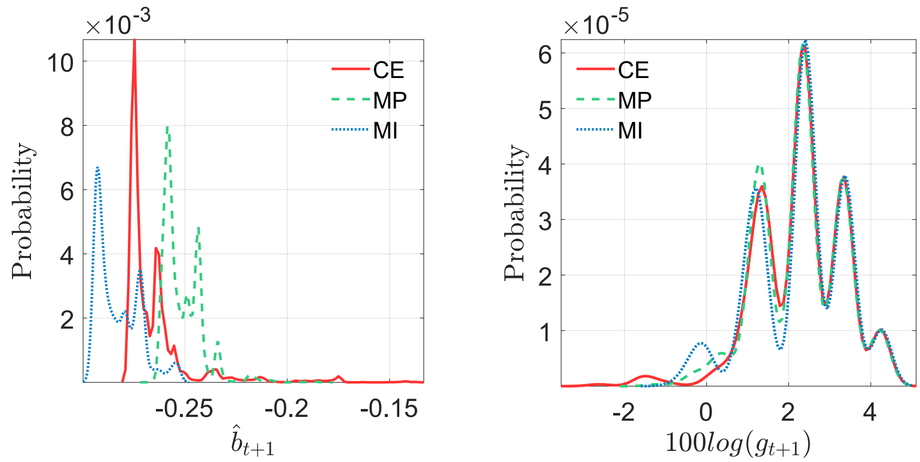


Figure 1.12: Event Window: CE, MP, and MI

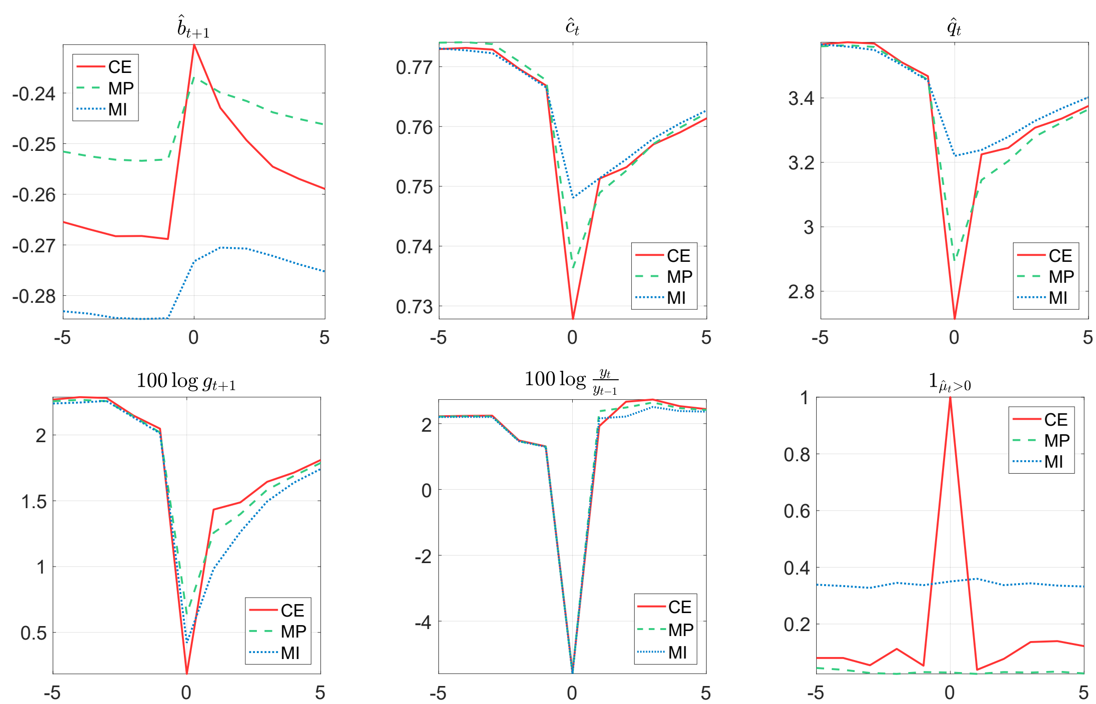


Figure 1.13: Transition Dynamics: CE, MP, and MI

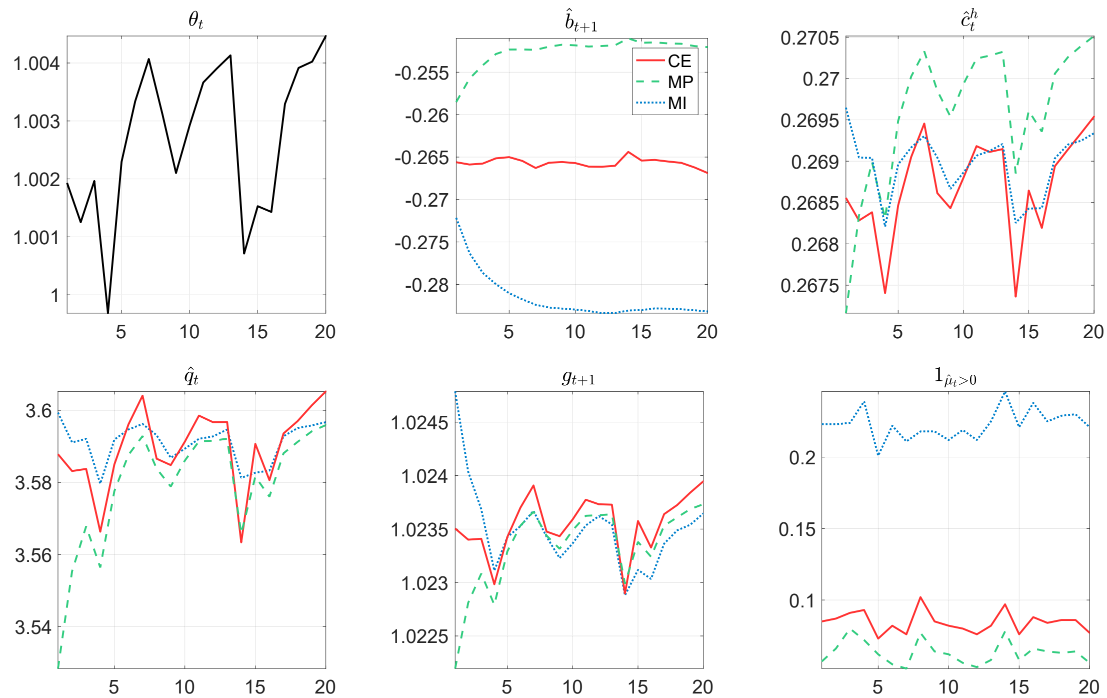


Figure 1.14: Policy Impacts on Average Growth: CE, MP, and MI

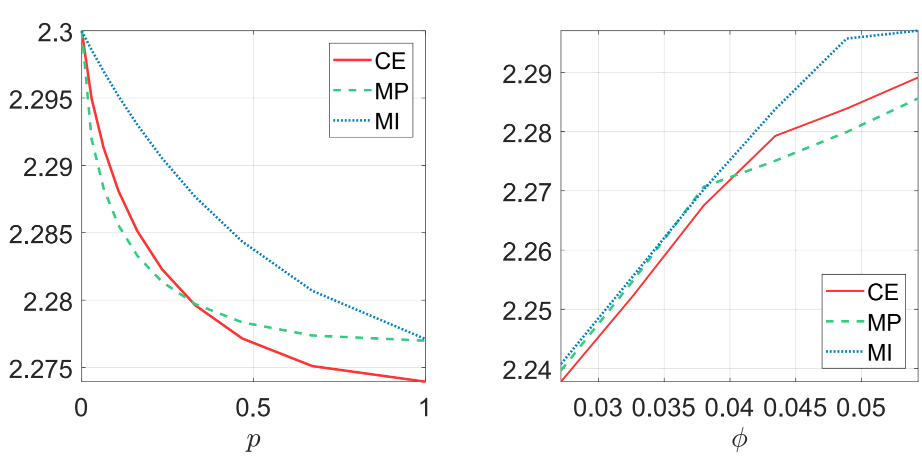


Figure 1.15: Welfare Gains (%): MI

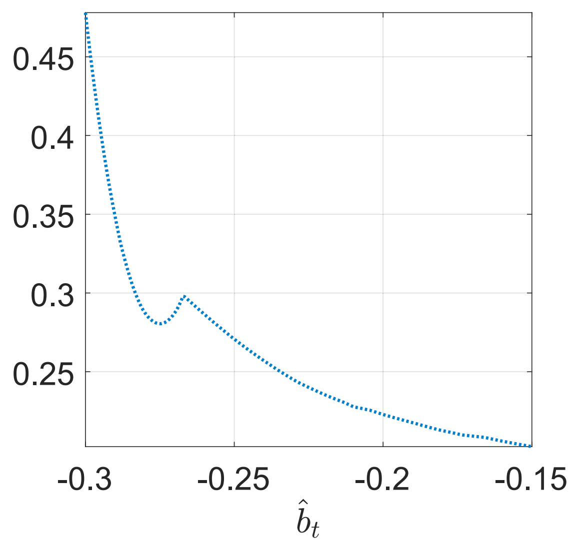
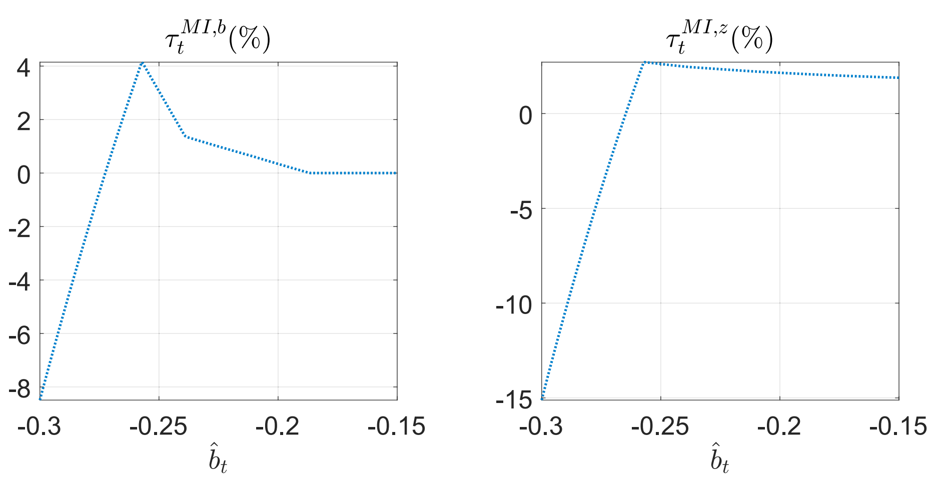


Figure 1.16: Two Instruments (%): MI



Chapter 2

Welfare Gains from Market Insurance: The Case of Mexican Oil Price Risk (with Fabian Valencia)

2.1 Introduction

The sharp decline in oil prices that started in late 2014 caught many oil-exporting countries off guard, but not Mexico. Following a long-standing practice, in the fall of 2014, the Ministry of Finance had purchased put options with one year maturity to hedge 228 million barrels of oil, about 28 percent of production, with a strike price of US$ 76.4 per barrel—US$ 31.1 above the actual average oil price in 2015.[1]

Sharp declines in oil prices have coincided with substantial fluctuations in economic activity and inflation (Husain et al., 2015). For net oil exporters, the negative consequences of the shock are also often amplified by rising risk spreads on sovereign debt (Baffes et al., 2015). In this context, designing policies to manage risks emerging from the exposure to commodity-price swings remains highly relevant, particularly for commodity exporters. Drawing on Mexico's experience, we assess the benefits and costs of using market insurance to hedge commodity price risk and enhance macroeconomic resilience. To this end, we augment a standard sovereign default model with access to put options —calibrated to Mexican data—to determine the size and main channels of welfare gains relative to a counterfactual scenario without put options. Our main contribution is the quantitative exploration of this question, exploiting complementarities between hedging instruments and defaultable debt.

Our benchmark economy is exposed to price risk of its commodity exports and can borrow through one-period defaultable debt acquired by risk-neutral foreign investors. The default decision and pricing of debt follows a willingness-to-pay framework à la Eaton and Gersovitz (1981). Since the country can default whenever it finds it optimal, bond prices fluctuate with the risk of default. The country can also purchase put options from risk-neutral foreign investors to lock in a minimum price for its commodity exports in the subsequent period. In the absence of put options, consumption

[1] The options were in the money in 2009 and 2016 as well.

smoothing takes place only through defaultable debt. The access to put options allows for additional benefits as they can help smooth income fluctuations arising from oil price volatility. But the upfront cost of put options also reduces consumption in the current period. In a simplified two-period version of the benchmark economy, we establish the aforementioned benefits—net of the cost of hedging—analytically.

After illustrating the main mechanisms in a simple model, we perform quantitative simulations in our full-fledged benchmark economy and compare our results to a version without put options. First, we find that using put options yields welfare gains[2] equivalent to a permanent increase in consumption of 0.44 percent. Second, we decompose these gains between those operating through a reduction of borrowing costs and those from income smoothing. The first channel emerges from the change in default incentives induced by the reduction in downside risks to income through put options. The second channel is similar to Lucas (1987), in which lower income fluctuations translate into a smoother consumption path, which increases welfare for risk averse agents. We conclude that about 90 percent of the welfare gains stem from the borrowing costs channel. Compared to the economy without hedging, risk spreads on debt are 19 basis points lower in the hedging economy.[3]

We also find that the welfare gains decline if the cost of the options includes a premium above the actuarially fair price. However, only a sizable premium would

[2]We define welfare gains as the improvement in the present discounted value of the utility derived from consumption.

[3]The welfare gains from income smoothing, at 0.04 percent, are very similar to what comes out of applying Lucas (1987)'s methodology to Mexican consumption series during 1996-2016.

reduce the welfare gains to zero. We also find that welfare gains increase with the strike price of put options, the hedged volume of oil, the volatility of oil prices, and with risk aversion of foreign investors. Finally, we find that selling oil forward can generate larger welfare gains than buying put options because they imply not incurring the upfront cost of insurance. However, political economy considerations cannot be ignored since forwards also imply giving up any revenue windfall if oil prices rise.[4]

Our paper contributes to the literature on welfare gains from market insurance with contributions including Caballero and Panageas (2008), who focus on optimal hedging strategies in countries facing risks of sudden stops in capital flows; and Borensztein et al. (2013) who examine the welfare gains from hedging through options and forwards in the presence of non-defaultable debt. Our paper differs from these studies by exploring synergies between hedging instruments and defaultable debt in increasing welfare. Furthermore, our paper is also related to studies examining the welfare gains from contingent debt, such as Hatchondo and Martinez (2012), who focus on GDP-indexed bonds, and Borensztein et al. (2017), who focus on catastrophic bonds. One closely related paper is Lopez-Martin et al. (2017), calibrated also to Mexican data. However, they model the government and the private sector separately and focus on the income-smoothing aspect of macro hedging. We model the economy as

[4]A clear example of political cost is Ecuador, cited in Daniel (2001), whose government conducted several hedging transactions through options and oil swaps in early 1993 that led to significant losses, ultimately triggering heavy criticism and even the appointment of a special committee to investigate allegations of corruption against the monetary authorities.

a whole and focus on understanding the sources of welfare gains from macro hedging, by looking at the relative importance of income smoothing and the relaxation of borrowing constraints as drivers of those gains. Finally, our paper is also related to the literature on quantitative models of sovereign default such as Aguiar and Gopinath (2006), Arellano (2008), and Hatchondo and Martinez (2009), although our focus is on the welfare gains from relying on hedging instruments as a complement to defaultable debt.

The paper is organized as follows: Section 2.2 describes Mexico's oil hedging program; Section 2.3 presents a two-period model to understand the benefits and costs of hedging; Section 2.4 presents the benchmark model; Section 2.5 presents quantitative results; Section 2.6 presents two extensions; and Section 2.7 concludes.

2.2 Mexico's Oil Hedging Program

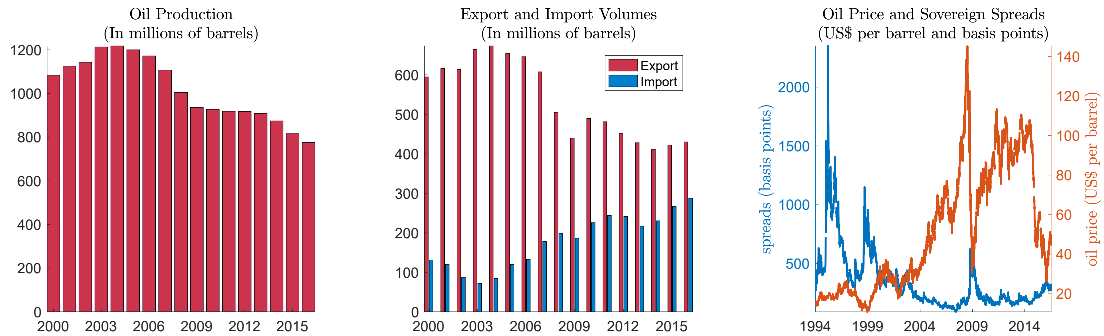
Mexico's government has systematically hedged oil-price risk for at least twenty years through a hedging program that is known to be the largest in the world (Blass, 2017). The program, as it is known today, was set up in 2001, (Duclaud and Garcia, 2012), although Mexico used market hedging instruments as early as 1990 (see Potts and Lippman (1991) and Daniel (2001)); however, details about those earlier operations are scarce. However, Mexico is not the only country that has used these instruments. Ecuador, Ghana, and more recently Uruguay are other examples of countries which have relied on hedging instruments to guard against oil-price volatility.

According to the U.S. International Energy Administration, Mexico is the 12th largest oil producer in the world. The oil sector is controlled by the fully state-owned company, Petroleos Mexicanos (PEMEX). Therefore, oil-related risks directly affect Mexico's public finances. This is the reason why the Mexican treasury conducts the hedging. On average, over 2000-2016, oil-related revenues represented 32 percent of total fiscal revenues, of which, 47 percent corresponded to oil exports, and the remainder to net domestic sales of petroleum products. Over the same period, oil exports averaged 11 percent of total exports. While the importance of oil for the economy and Mexico's public finances has declined since the mid-2000's,[5] oil revenues still represented about 16 percent of total fiscal revenues and close to 5 percent of total exports in 2016. Moreover, there is a high negative correlation between risk spreads on external sovereign debt and oil prices, with a correlation coefficient of -0.59 over the past twenty years (Figure 2.1). A 2013 constitutional reform opened the oil sector to private investment, but the private oil sector remained in its infancy as of end-2017. However, it is expected to gain importance as private investment picks up and new oil fields are exploited, which would eventually reverse the declining importance of oil in the economy.[6]

[5]The decline has been the result of falling oil production due to aging oil fields, lower oil prices since 2014, and higher non-oil tax revenues from a tax reform in place since 2014.

[6]A description of the reform that opened the energy sector to private investment and its potential implications for future oil production can be found in IMF (2014).

Figure 2.1: Oil Production, Oil Prices, and Sovereign Spreads



Source: INEGI.

The Mexican treasury conducts hedging operations with the main objective of reducing the risk of fiscal revenue shortfalls during any given fiscal year. Specifically, the Mexican treasury includes in its annual budget an assumption on the export price of its oil for the subsequent fiscal year, computed as the weighted average between historical prices and futures. To reduce the risk of a decline in oil-related revenues, the Mexican treasury purchases Asian put options with strike price equal or close to the oil price assumed in the budget. The use of Asian options allows the treasury to lock in a minimum price for the whole fiscal year.[7] The program is executed through several contracts with foreign banks as counterparts. Most of the contracts include Maya oil, a type of Mexican heavy crude oil, as underlying asset, but a small

[7] An American or European put option is exercised if the spot price on a particular day exceeds the strike price. In contrast, an Asian put option is exercised if the average spot price for a pre-determined period, which in the case of Mexico is one year, exceeds the strike price. In this way, Mexico guarantees a minimum average price of oil for the whole fiscal year.

fraction of contracts use the Brent as underlying asset. Maya oil dominates because it represents about 80 percent of Mexico's oil export volumes.

While on average, Mexico produced 1 billion barrels annually over 2000-2016, of which it exported roughly half, Mexico also imported about 178 million barrels of petroleum products annually, over the same period. The domestic sale of imported petroleum products at regulated prices, which did not move one-for-one with international prices, compensated losses (or gains) in crude oil export revenues that resulted from fluctuations in international oil prices.[8] After taking these offsetting factors into account, the Mexican treasury hedged, on average, 29 percent of total production over the past 10 years.

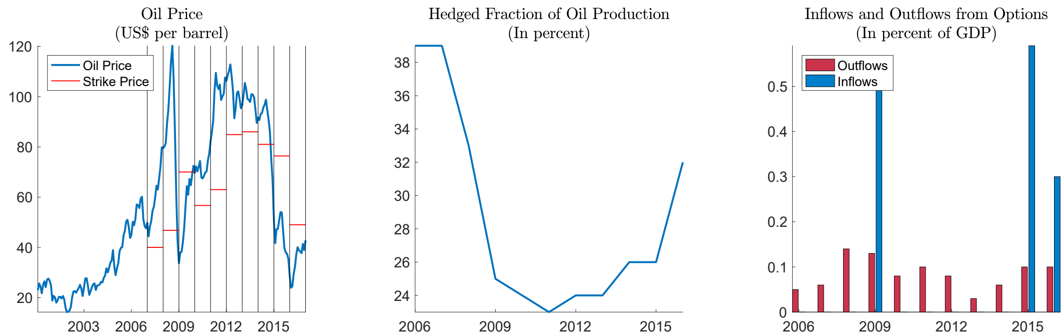
Since 2001, the cost of the options has averaged 0.1 percent of GDP per year and they have been exercised only in three occasions: in 2009, 2015, and 2016, with payoffs reaching 0.5, 0.6, and 0.3 percent of GDP respectively (Figure 2.2).

2.3 Benefits/Costs of Hedging in a Two-period Model

Before proceeding to the quantitative analysis, we use a simple two-period model, $t \in \{0, 1\}$ to illustrate analytically the benefits and costs of hedging and its comple-

[8] A process of liberalization of domestic fuel prices began in 2016 and was completed by end-2017.

Figure 2.2: Mexico's Oil Hedging Program



Source: INEGI and authors' calculations.

mentarities with defaultable debt. Consumers choose in period 0 how much to issue in bonds d at a price q as to maximize the present discounted value of utility derived from consumption, with discount factor $\beta < 1$. Income is given by y in period 0 while it can take values y^H or $y^L < y^H$ in period 1, with probabilities p and $1-p$, respectively. After income uncertainty is realized in period 1, consumers can default on their bonds, in which case income equals $y^{def} > 0$. The maximization problem is summarized by

$$
\begin{aligned}
U_0 \quad = \quad & \max_d \ \log c_0 + \beta E_0 \log c_1 \\
\text{s.t.} \quad & c_0 = qd + y \\
& c_1^i = \max\left\{y^i - d, y^{def}\right\}, i \in \{H, L\}
\end{aligned}
$$

where for simplicity we assume $u(c) = \log c$. Assuming that the risk-free rate, r^*, equals zero, risk-neutral foreign investors acquire the bonds at a price that satisfies

$$q = \begin{cases} 1, & \text{if } y^L - d \geq y^{def}; \\ p, & \text{if } y^L - d < y^{def} \leq y^H - d; \\ 0, & \text{if } y^H - d < y^{def}, \end{cases}$$

where the first condition implies that risk spreads are zero because in those circumstances default is never optimal. The second condition states that consumers always default under a bad realization of income in period 1, in which case $q = p < 1$. Finally, the third condition implies that the bond is worthless since the consumers would default with probability 1 as it is always optimal to do so. We now introduce hedging in this framework. Suppose that the consumer buys insurance in period 0 that guarantees a level of income of at least $\bar{y}$ in period 1 at a cost ξ that satisfies

$$\xi = \begin{cases} p(\bar{y} - y^H) + (1-p)(\bar{y} - y^L), & \text{if } \bar{y} \geq y^H; \\ (1-p)(\bar{y} - y^L), & \text{if } y^L < \bar{y} < y^H; \\ 0, & \text{if } \bar{y} \leq y^L. \end{cases}$$

Given the structure of put options, the problem for the economy becomes

$$
\begin{aligned}
U_0^{hedge} &= \max_d \log c_0 + \beta E_0 \log c_1 \\
\text{s.t.} \quad & c_0 = qd + y - \xi \\
& c_1^i = \max\left\{\max\{\bar{y}, y^i\} - d, y^{def}\right\}, i \in \{H, L\}
\end{aligned}
$$

Role of Hedging. Let us first assume that the insured level of income, $\bar{y}$, equals the unconditional mean of period-1 income, that is $\bar{y} = py^H + (1-p)y^L$. Hedging plays first an income-smoothing role by reducing income fluctuations in period 1 since $y^L < \bar{y} < y^H$ and with hedging, period-1 income is either $\bar{y}$ or y^H. Second, hedging can alter default and borrowing incentives, but not necessarily in an unambiguous way. In the following propositions we demonstrate the various implications of hedging for default incentives and welfare.

Proposition 3. Default Incentives and Hedging

Consider an economy with no hedging in which $\hat{y}^{def}$ and $\hat{\hat{y}}^{def}$ are such that consumers never default if the income loss from default is too large, i.e. $y^{def} < \hat{y}^{def}$; they always default if the income loss from default is too small, i.e. $y^{def} > \hat{\hat{y}}^{def}$; and they only default after a low realization of income if the income loss from default is neither too large nor too small, $y^{def} \in (\hat{y}^{def}, \hat{\hat{y}}^{def})$. Introducing hedging in this economy increases $\hat{y}^{def}$ and reduces $\hat{\hat{y}}^{def}$.

Proof. See Appendix B.2.1. □

Intuitively, Proposition 3 states that hedging can change default thresholds, by either improving or worsening incentives to default. The direction in which those incentives change depends on how costly it is to default. When default is so costly so that it never happens (i.e. the farthest left region in Figure 2.3, $y^{def} < \hat{y}^{def}$), hedging does not affect default incentives. Reduce default costs a bit and we enter the middle region, i.e. $y^{def} \in (\hat{y}^{def}, \hat{\hat{y}}^{def})$, where changes in the default thresholds can lead to the economy to never default or to always default. In the former case, the result follows from the fact that hedging helps secure a minimum income—above the default level—and therefore reduces incentives to default and the cost of debt. In the latter case, the income under default is higher, and therefore default is less costly. Because hedging requires increasing borrowing to pay for the upfront cost of insurance, it may worsen default incentives given that it is not so costly to default. The farthest right region is in the proposition for completeness only. In this region, the cost of default is so small that the economy would always default. Therefore, it is not an interesting case to analyze since no creditor would lend to consumers who would default with probability 1. In the following propositions, we analyze the implications for welfare under all these cases except for the last one.

Proposition 4. No Default in Equilibrium

When default is too costly, such that the economy does not default in equilibrium, introducing hedging increases social welfare and the country borrows more.

Proof. See Appendix B.2.2. □

In this case, hedging is clearly beneficial. Income becomes smoother and the economy can afford to borrow more. This insight is similar to the work by Borensztein et al. (2013) who derived welfare implications of hedging in a world with non-defaultable debt.

Proposition 5. Default Only When Income is Low

When the economy defaults only when $y = y^L$, whether hedging increases or decreases welfare depends on its impact on default incentives:

1. *if hedging reduces default incentives, hedging increases welfare, but borrowing might increase or decrease.*
2. *if hedging does not change default incentives, it reduces welfare and increases borrowing.*
3. *if hedging increases default incentives, both social welfare and borrowing decline.*

Proof. See Appendix B.2.3. □

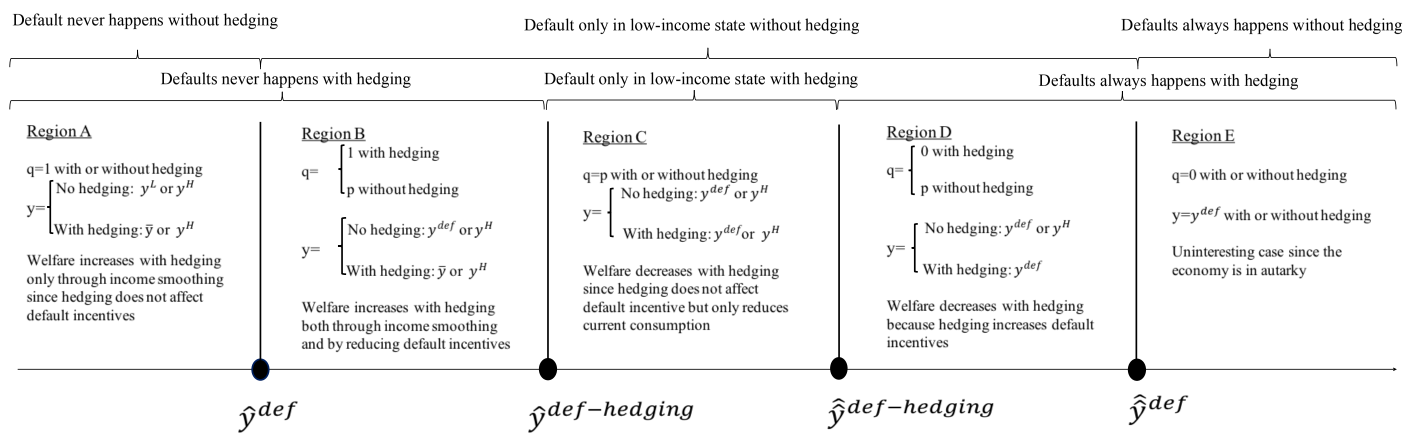
In case 1, both the income-smoothing and borrowing cost channels imply a welfare gain despite the upfront cost of insurance. However, the impact of hedging on borrowing is ambiguous: On the one hand, more borrowing is desirable to purchase insurance; on the other hand, more borrowing increases the likelihood of default and hence the cost of debt, ultimately reducing incentives to borrow.

In case 2, hedging ensures higher income in the low state of the world than in absence of hedging, only if there is no default; however, if the economy defaults when $y = y^L$, hedging does not change default incentives, nor the level of income since default implies the same level of income under default, y^{def}, as the no-hedging economy. In this case, consumers borrow more in period 0 to purchase insurance, but income in period 1 is the same with or without hedging. As a result, hedging only lowers current disposable income and reduces welfare.

In case 3, if hedging increases default incentives it clearly reduces welfare since it would imply that the economy moves from the region where it only defaults in the bad state of nature to the region where it always defaults.

Figure 2.3 summarizes key insights from the above propositions. The left regions in the figure correspond to areas where the cost of default is high. In these regions, hedging is always desirable either because both, the borrowing costs channel and the income smoothing channel are at work, which is the case when hedging reduces default risk, or because only the income smoothing channel is at work, which is the case when there is no default in equilibrium. The model also includes regions where hedging reduces welfare because the costs of default are small. However, the fact that defaults are rare events —Mexico has defaulted only 8 times since 1821 —and the empirical literature documents significant output losses following sovereign defaults, the left regions in Figure 2.3 are likely to be the more empirically relevant cases. We resort now to our quantitative analysis to shed light on the size of welfare gains from hedging.

Figure 2.3: Two-period Model



Source: Authors' construction.

2.4 Model Economy

The question of welfare gains from hedging commodity price risk has been explored in models with non-defaultable debt (Borensztein et al., 2013, 2017). Since default risk is in practice not zero, our departure point is a standard sovereign default model as in Aguiar and Gopinath (2006) and Arellano (2008). In this economy, a country can issue one-period bonds in international credit markets on which the country can default when it finds it beneficial to do so. But default is costly. A default implies losing access to international credit markets, although not permanently, and lower income. There is only one source of risk in this economy: oil prices. In addition to issuing defaultable debt, the country can acquire put options to hedge oil price risk in international financial markets. The quantitative assessment of the welfare gains from using put options will be conducted by comparing outcomes with and without put options.

2.4.1 Benchmark Model with Defaultable Debt and Put Options

The economy is populated by infinitely-living, risk-averse representative agents who make decisions in order to maximize the expected present discounted value—

with discount factor β—of the utility derived from consumption:

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\frac{C_t^{1-\gamma}}{1-\gamma}\right] \tag{2.1}$$

where risks preferences of the consumer are represented by a standard constant relative risk aversion (CRRA) utility function with coefficient of risk aversion γ.

Total income in this economy, Y_t, has two components: non-oil income (F_t) and oil income (X_t),

$$Y_t = F_t + X_t \equiv F_t + p_t Q_t \tag{2.2}$$

where p_t and Q_t are the price and quantity of oil production respectively. The only source of risk in this economy is the price of oil, p_t, which is assumed to follow an autoregressive stochastic process, to be defined momentarily. We assume that non-oil income, F_t, grows deterministically at a constant rate G in every period. We normalize all variables by F_t and denote them with lower letters:

$$y_t \equiv \frac{Y_t}{F_t} = 1 + p_t\frac{Q_t}{F_t} \equiv 1 + p_t\mathcal{Q} \tag{2.3}$$

$$E_0\left[\sum_{t=0}^{\infty}(\beta G^{1-\gamma})^t\frac{c_t^{1-\gamma}}{1-\gamma}\right] \tag{2.4}$$

where $\mathcal{Q} = \frac{Q_t}{F_t}$ and $c_t = \frac{C_t}{F_t}$ denote normalized oil production and consumption. To further simplify the exposition, we assume that $\mathcal{Q}$ is constant, which as we will discuss in the calibration section, it is not an inaccurate representation of the data. From now on we will focus on the normalized problem knowing that the original problem can always be recovered by multiplying normalized variables by F_t (See Appendix B.1 for details).

In every period, consumers have an initial level of wealth, w_t, composed by income, y_t, and bonds, b_t, acquired in the previous period: $w_t = y_t + b_t$. Consumers allocate this wealth among consumption, c_t; zero-coupon one-period bonds, b_{t+1}, which they can acquire in international credit markets at a price q_t; and put options acquired in international financial markets at a unit price $\xi(\bar{p}_t)$, which entitles them to sell a fraction $\alpha\mathcal{Q}$ of oil production in period $t+1$ at a pre-determined strike price $\bar{p}_t$.[9]

$$c_t + q_t G b_{t+1} + \alpha \mathcal{Q} G \xi(\bar{p}_t) = w_t \tag{2.5}$$

where b_{t+1} can take positive or negative values reflecting whether the country lends or borrows in international credit markets. The consumer arrives to the following period, $t+1$, with wealth w_{t+1}, given by

$$w_{t+1} = y_{t+1} + \alpha \mathcal{Q} \max\{\bar{p}_t - p_{t+1}, 0\} + b_{t+1} \tag{2.6}$$

where $\alpha\mathcal{Q}\max\{\bar{p}_t - p_{t+1}, 0\}$ reflects the fact that the put options locked in a minimum price, $\bar{p}_t$, for the hedged fraction of oil production. The optimization problem, under

[9] $\alpha \in (0, 1)$ captures the fact that Mexico hedges only part of production, as discussed in the previous section

no default, is summarized by

$$
\begin{aligned}
V^c(w_t, p_t) \quad &= \quad \max_{c_t, b_{t+1}} \frac{c_t^{1-\gamma}}{1-\gamma} + \beta G^{1-\gamma} E_t \left[V(w_{t+1}, p_{t+1}) \right] \\
\text{s.t.} \quad & \quad c_t + q_t G b_{t+1} + \alpha \mathcal{Q} G \xi(\bar{p}_t) = w_t \\
& \quad w_{t+1} = y_{t+1} + \alpha \mathcal{Q} \max\{\bar{p}_t - p_{t+1}, 0\} + b_{t+1}
\end{aligned}
\tag{2.7}
$$

where $V^c(w_t, p_t)$ denotes the value function under continuation or no default, with the state of the economy summarized by two state variables, $\{w_t, p_t\}$.

Default Decision. In every period, consumers can default on their debt, in which case the economy gets excluded from international financial markets. While in default, consumers cannot borrow nor purchase put options and the economy resorts to financial autarky. Besides the exclusion from international financial markets, default implies an income loss $h(y_t)$ in every period, reflecting the assumption that credit plays an essential role in the economy. This assumption can be justified by the existence of a minimum scale for some investment projects that would not be reached without external financing, preventing those investments from being carried out. Alternatively, the exclusion from international financial markets may obstruct the normal conduct of business of companies operating with non-residents by reducing or eliminating the access to financial services that may be essential to their activity, such as trade finance. The assumption ultimately aims at capturing output losses often linked to sovereign default episodes (e.g. Laeven and Valencia, 2013 and

Gornemann, 2014). A default status does not imply permanent exclusion from financial markets. It is assumed that in any given period, there is a probability $\lambda \in (0, 1)$ that the economy is "redeemed" and re-enters international credit markets with zero net assets.

Denoting the value function under default as $V_t^d(p_t)$, the problem for an economy that has defaulted becomes

$$\begin{aligned} V^d(p_t) \quad &= \quad \frac{c_t^{1-\gamma}}{1-\gamma} + \beta G^{1-\gamma}\left[\lambda E_t V(w_{t+1}, p_{t+1}) + (1-\lambda) E_t V^d(p_{t+1})\right] \qquad (2.8) \\ \text{s.t.} \quad & c_t = y_t - h\left(y_t\right) \\ & w_{t+1} = y_{t+1} \end{aligned}$$

where $V(w_t, p_t) = \max\left(V^c(w_t, p_t), V^d(p_t)\right)$ reflects that default happens if and only if $V^d(p_t) > V^c(w_t, p_t)$.

Risk-Neutral Foreign Investors. We assume that there is a continuum of risk-neutral foreign investors who can purchase bonds or sell put options to consumers in the benchmark economy. If default happens, foreign investors do not recover any value from the bonds and renege to honor the put options. However, for simplicity, any value foreign investors recover by reneging to honor the options is assumed to be consumed in transaction costs or legal fees. Consequently, recovery values are assumed at zero in the pricing of the bonds. Note that this assumption may ultimately understate the welfare gains from hedging as these recoveries, if not zero, could lead to lower risk spreads on debt.

Denoting r^* the world risk-free rate and $D(w_{t+1}, p_{t+1})$ an indicator default function which equals one if default happens and zero otherwise, no-arbitrage conditions require that

$$
\begin{aligned}
q(b_{t+1}, p_t) &= \frac{E_t\left[1 - D(\underbrace{y_{t+1} + \alpha \mathcal{Q} \max\{\bar{p}_t - p_{t+1}, 0\} + b_{t+1}}_{w_{t+1}}, p_{t+1})\right]}{1 + r^*} \\
\xi(\bar{p}_t) &= \frac{E_t[\max\{\bar{p}_t - p_{t+1}, 0\}]}{1 + r^*}
\end{aligned}
\tag{2.9}
$$

The above equations imply that the expected return to the foreign investor from holding bonds or being the counterpart of a put option are equalized and given by the risk-free return. Hedging income appears in the default function, affecting the price of bonds and the risk spreads.

2.4.2 An Economy without Put Options

The benchmark economy includes the availability of put options because the model will be calibrated to Mexican data over a period where Mexico hedged oil price risk through these instruments. To quantify gains from hedging, we setup a counterfactual economy with no access to put options. To differentiate these two economies, we use a tilde over variables that correspond to the no-hedging economy. State variables

$\{w_t, p_t\}$ are defined in the same way as before and value functions are given by

$$\tilde{V}(w_t, p_t) = \max\left(\tilde{V}^c(w_t, p_t), \tilde{V}^d(p_t)\right)$$

where $\tilde{V}^c(w_t, p_t)$ and $\tilde{V}^d(p_t)$ denote the value functions of continuation and default respectively.

As before, the problem under no default or continuation is given by

$$\begin{aligned} \tilde{V}^c(w_t, p_t) \quad &= \quad \max_{c_t, b_{t+1}} \frac{c_t^{1-\gamma}}{1-\gamma} + \beta G^{1-\gamma} E_t\left[\tilde{V}(w_{t+1}, p_{t+1})\right] \\ \text{s.t.} \quad & c_t + \tilde{q}_t G b_{t+1} = w_t, \\ & w_{t+1} = y_{t+1} + b_{t+1}, \end{aligned} \tag{2.10}$$

where $\tilde{q}_t$ is the price of the bond in the no-hedging economy. Note also the absence of the terms related to the purchase and exercise of options in the budget constraint equations. Under default, we have

$$\tilde{V}^d(p_t) \quad = \quad \frac{[y_t - h(y_t)]^{1-\gamma}}{1-\gamma} + \beta G^{1-\gamma}\left[\lambda E_t \tilde{V}(w_{t+1}, p_{t+1}) + (1-\lambda) E_t \tilde{V}^d(p_{t+1})\right] \tag{2.11}$$

The pricing of bonds follows the same structure as before:

$$\tilde{q}(b_{t+1}, p_t) = \frac{E_t\left[1 - \tilde{D}(y_{t+1} + b_{t+1}, p_{t+1})\right]}{1 + r^*} \tag{2.12}$$

2.4.3 Recursive Equilibrium

As it is standard in the sovereign default literature, we solve the problem from the perspective of a benevolent government, who makes the decision on behalf of private agents in the economy. In what follows we define the recursive equilibrium in this economy.

Definition 2. *Markov Perfect Equilibrium*

1. *The Markov Perfect Equilibrium of our benchmark model is characterized by a set of value functions* $\{V(w_t, p_t), V^c(w_t, p_t), V^d(w_t, p_t)\}$*, default function* $D(w_t, p_t)$*, consumption function* c_t*, next period bond holding* b_{t+1}*, and bond price* q_t *such that given the state variables* $\{w_t, p_t\}$*, the cost of put options* $\xi(\bar{p}_t)$*, and the strike price* $\bar{p}_t$*, they solve the optimization problems (2.7) and (2.8). Furthermore,* $V(w_t, p_t) = \max\left(V^c(w_t, p_t), V^d(p_t)\right)$ *and the price* q_t *satisfies equation (2.9).*

2. *The Markov Perfect Equilibrium of the economy without put options is characterized by a set of value functions* $\{\tilde{V}(w_t, p_t), \tilde{V}^c(w_t, p_t), \tilde{V}^d(w_t, p_t)\}$*, default function* $\tilde{D}(w_t, p_t)$*, consumption function* $\tilde{c}_t$*, next period bond holding* $\tilde{b}_{t+1}$*, and bond price* $\tilde{q}_t$ *such that given the state variables* $\{w_t, p_t\}$*, they solve the optimization problems (2.10) and (2.11). Furthermore,* $\tilde{V}(w_t, p_t) = \max\left(\tilde{V}^c(w_t, p_t), \tilde{V}^d(p_t)\right)$ *and the price* $\tilde{q}_t$ *satisfies equation (2.12).*

2.5 Quantitative Analysis

2.5.1 Calibration

We calibrate the benchmark model to Mexican data over 1996-2016, a period during which Mexico used put options to hedge oil price risk. The benchmark model has 13 parameters, which we split in three groups before assigning values.

The first group of parameters, comprising $\{r^*, \gamma, \lambda, p, \rho, \sigma, \mathcal{Q}, \alpha, G\}$, are directly taken from the literature or data. The real risk-free interest rate, r^*, equals the average over 1996-2016 of the nominal yield on 1-year U.S. treasury bills, converted to real terms using the U.S. GDP deflator, resulting in a value of 0.64 percent. The risk aversion parameter, γ, is set at 2, the standard value found in the literature. The probability of returning to international financial markets after having defaulted, λ, is calibrated to match the duration of default episodes for Mexico. To get this number, we examine a much longer time period, covering 1821-2016, over which Mexico defaulted 8 times. On average, the duration of default episodes is 9.38 years, which suggests a value of λ equals to 0.11.[10] The parameters of the oil-price process, p, ρ, σ, are obtained from estimating a log AR(1) process of the following form

$$\log p_t = (1-\rho)\left[\log(p) - \frac{1}{2}\frac{\sigma^2}{1-\rho^2}\right] + \rho \log p_{t-1} + \varepsilon_t \tag{2.13}$$

[10]The default data are taken from Carmen Reinhart's website. See `http://www.carmenreinhart.com/data/browse-by-topic/topics/7/`.

where the unconditional mean p, the persistence parameter ρ, and volatility σ are estimated using a Maximum Likelihood Estimator (MLE) described in Appendix B.4 over the period 1996-2016. To complete the calibration of the income process, we use actual quantities of Mexican oil production, which over 1996-2016 averaged 1.03 billion barrels per year. Non-oil income, F_t, is approximated by non-oil GDP—measured as total Mexican GDP after subtracting oil and gas extraction. Since the model is written in terms of one tradable good, we convert F_t to U.S. dollars using market exchange rates, and then to real terms using the U.S. GDP deflator. The deterministic annual real growth rate, G, of non-oil income is computed as the average growth of non-oil income over 1996-2016, resulting in a value of 3.13 percent. We calculate the normalized value of oil production, $\mathcal{Q}$, by dividing oil GDP by non-oil income and the oil price. In the model, we are assuming that this ratio is constant, equal to 0.1 percent, which is not a significant departure from the data. This ratio was fairly stable over 1996-2016, ranging between 0.1 percent and 0.2 percent. The fraction of oil production hedged, α, is set at 29 percent, which corresponds to the average fraction of production hedged by Mexico over 2006-2016. We consider this range only because of lack of publicly available data on the actual fraction hedged prior to 2006.

The second group of parameters, comprising $\{\beta, y^*\}$, is chosen to match relevant moments in the data. In selecting the output loss from default, we follow Arellano (2008) who adopts an asymmetric output cost function which delivers default rates and spreads within the range seen in the data. To this end, the output loss function is given by

$$h(y_t) \quad = \quad \begin{cases} y_t - y^*, & \text{if } y_t \geq y^*, \\ 0, & \text{if } y_t < y^*. \end{cases}$$

We choose β and y^* to match two empirical moments: (1) the Mexican government's gross financing needs—defined as the overall fiscal deficit in any given year plus debt rollover needs—to non-oil fiscal revenue ratio over 2006-2016, of 11.90 percent, a definition of debt that most closely matches the definition of debt in the model; (2) the average risk spreads on sovereign debt over 2000-2016, 1.48 percent. Risk spreads are calculated as the difference between the yield in dollars on Mexico's 1-year government bonds and the yield on U.S. 1-year treasury bills. We compute the average over 2000-2016 to avoid distortions from the sharp increase in spreads around the Tequila crisis of 1995.

The last group of parameters includes the cost and strike price of the options, $\{\xi(\bar{p}_t), \bar{p}_t\}$. As discussed in Section 2.4 the price is determined by a risk-neutral pricing condition and therefore it emerges endogenously once other parameters in the model have been determined. The exact implementation of the pricing function is given in Appendix B.5. The strike price is chosen to match the conditional mean of the oil price. While we have data for the actual strike price chosen by Mexico, the sample is too short to estimate a robust empirical relationship between the strike price and the actual oil price. Instead, we proceed as follows. First, we assume that

$\bar{p}_t = \mu E_t[p_{t+1}|p_t]$, with the goal of capturing Mexico's actual choice for the strike price, which intends to be close to the oil price assumed in the budget for the subsequent year. This budget oil price is in turn determined by a weighted average between past and future prices implied by forward contracts, which aims at capturing the long-run price of oil, given current market conditions. Second, we choose a value of μ such that the simulated long-run probability of exercising the options is 18.75 percent, consistent with the fact that between 2001 and 2016, the Mexican government exercised the options only 3 times. The approach yields a value of μ equal to 0.77. To cross check that this approach does not result in a number significantly different than the one implied by the data, we compute μ directly from the data by dividing the actual strike price by the average oil price in the year when the options where purchased (Table 2.1). This alternative approach returns an average value for μ of 0.85, close to the value of 0.77 used in the baseline calibration.

Table 2.1: Actual Strike Prices from Options

Years	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Strike price (Nominal US$)	40.00	46.80	70.00	56.69	63.00	84.90	86.00	81.00	76.40	49.00	38.00	62.89
Conditional mean of oil price (Nominal US$)	51.75	53.98	88.86	54.82	69.93	91.86	103.87	99.76	93.80	55.29	51.69	74.15
Ratio to conditional price mean (μ)	0.77	0.87	0.79	1.03	0.90	0.92	0.83	0.81	0.81	0.89	0.74	0.85

Source: Auditoria Superior Federal and authors' calculations.

Finally, it is important to note that a period in this model corresponds to one year, and all values are expressed in 2009 constant U.S. dollar terms. All parameter values are reported in Table 2.2. The bottom part of the table shows that the model-simulated moments are very close to their data counterparts. It is worth noting also that while our discount factor, at 0.76, appears low for an annual frequency, values in this range are found in the literature, for example Yue (2010) chooses a discount rate at 0.72. It is well-known that sovereign default models with one-period bonds have difficulty in matching both default spreads and debt ratios simultaneously. To achieve both goals, we have to pick a lower value for the discount factor.

Table 2.2: Parameters

Parameters	Value	Source
Risk-free rate	$r^* = 0.64\%$	U.S. real interest rate
Risk aversion	$\gamma = 2$	Standard value
Probability of redemption	$\lambda = 0.11$	Average years in default
Growth rate	$G = 1.0313$	Data
Unconditional mean	$p = 54.60$	Data
Persistence	$\rho = 0.71$	Data
Volatility	$\sigma = 0.25$	Data
Oil to non-oil GDP ratio	$p\mathcal{Q} = 6\%$	Data
Strike price	$\bar{p}_t = \mu E_t[p_{t+1}\|p_t] = 0.77E_t[p_{t+1}\|p_t]$	Prob of exercising options
Hedging share	$\alpha = 0.29$	Data
Hedging cost	$\xi(\bar{p}_t)$	Risk-neutral pricing
Discount rate	$\beta = 0.76$	Match debt ratio
Output loss function	$y^* = 0.98E[y] = 1.03$	Match spreads
Target Moments	Data	Model Simulation
Debt-GDP ratio	11.90 %	11.97 %
Sovereign spreads	1.48%	1.40 %

Source: INEGI, Federal Reserve Board of Governors, and authors' calculations.

We solve the model numerically using value function iteration with the algorithm described in more detail in Appendix B.3. We use Rouwenhorst method as in Kopecky and Suen (2010) to determine the grid for oil prices. Specifically, we use 21 and 500 grids to approximate oil price and bond holdings respectively.

2.5.2 Welfare Gains from Hedging

We measure welfare gains from hedging by comparing the utility derived from the stream of consumption under the benchmark economy, and the one in the no-hedging economy. We follow the standard convention in the literature of expressing the welfare gains in terms of a permanent increase in annual consumption. Formally, the definition is given in equation (2.14).

$$\Delta(w_t, p_t) = 100 * \left[\left(\frac{V(w_t, p_t)}{\tilde{V}(w_t, p_t)} \right)^{\frac{1}{1-\gamma}} - 1 \right] \tag{2.14}$$

Under this definition, welfare gains are conditional on the values of the state variables, $\{w_t, p_t\}$; therefore, we refer to $\Delta(w_t, p_t)$ as conditional welfare gains.[11] Furthermore, we also define unconditional welfare gains by $E[\Delta(w_t, p_t)]$, where the expectation is taken with respect to the state variables using their ergodic distribution under the benchmark economy.[12] To compute the welfare gains, we first run 100 Monte Carlo simulations of 2,000 periods each for the benchmark economy. We draw oil prices from the estimated stochastic process, given some initial price. This initial condition, together with one for wealth, and the optimal solutions for consumption and borrowing determine the optimal value of these variables for the current period. We then check if default is optimal or not, to then proceed to use the law of motion for

[11] Note that $\Delta(w_t, p_t)$ does not depend on any particular time t. We keep the time script t for consistency of notation.

[12] Using instead the ergodic distribution under the economy without hedging yields similar outcomes.

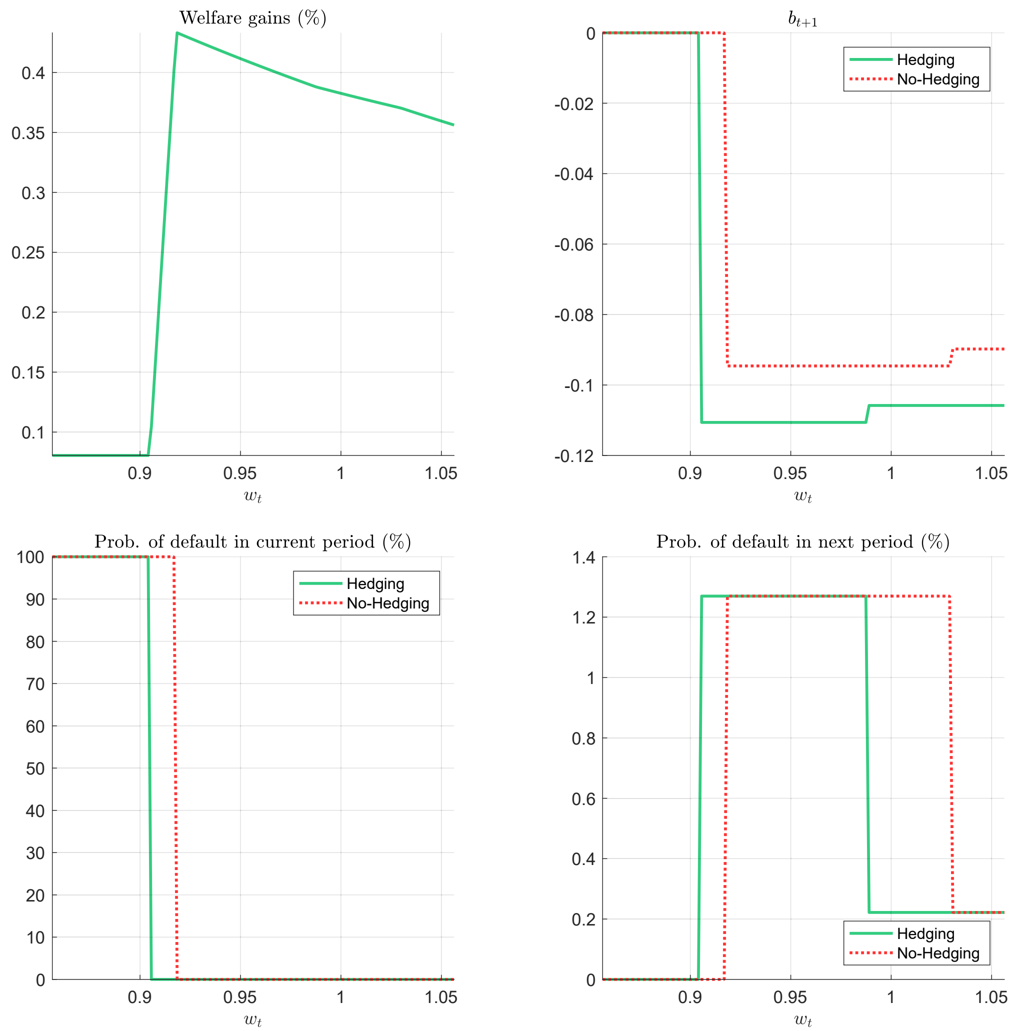
wealth and oil prices to determine the value of the state variables for the subsequent period and so on. We repeat this process until we reach 2,000 periods. We throw away the initial 500 periods and approximate welfare—or the value function—by computing the present discounted value of the utility derived from the simulated path for consumption. We construct the counterpart value function for the economy without hedging, using the same procedure and initial conditions for w_t and p_t.

In Figure 2.4 we show the conditional welfare gains $\Delta(w_t, p_t)$; bond purchase/sale b_{t+1}; the probability of default in the current period t; and the probability of default in the next period $t+1$, given by $E[D(y_{t+1} + b_{t+1}, p_{t+1})|p_t]$; for different values of state variable w_t, and after setting the price of oil, p_t, equal to its unconditional mean. These conditional welfare gains vary from 0 to a 0.45 percent permanent increase in consumption. When the economy has less wealth to start, default incentives are strong, the probability of default in current period t is high, and welfare gains from hedging are small. In this region, hedging does little to improve welfare since default happens regardless, analogous to the result in the farthest right region of Figure 2.3. When the economy is less indebted, default incentives weaken and the probability of default declines, but more quickly for the economy with hedging than for the one without it. For values of wealth w_t between 0.91 and 0.92, the economy without hedging defaults in the current period, but the economy with hedging does not. This region is analogous to region B in Figure 2.3. In this region, welfare jumps from close to 0 to 0.43 percent. As wealth increases, welfare gains decline as default becomes less and less relevant. At some point, even the no-hedging economy does not default in the current period and it has the same default probability in the next period as the hedging economy. Welfare declines further since hedging is costly and its benefit through a reduction in borrowing costs is much lower. This result is analogous to the result depicted in the left regions of Figure 2.3.

We also find unconditional welfare gains equivalent to a permanent increase in annual consumption of 0.44 percent. These gains are within the range found by related studies. Borensztein et al. (2017) finds that the unconditional welfare gains from using catastrophe (CAT) bonds, in the presence of defaultable debt, are typically small: less than 0.12 percent. They rationalize their results by claiming that the CAT bonds do not change the default threshold. Hatchondo and Martinez (2012) explore the welfare gains from issuing GDP-indexed bonds in a model with defaultable debt. They find that GDP-indexed bonds could change the default threshold and find welfare gains equivalent to a permanent increase in consumption of 0.46 percent.

Source of Welfare Gains. As discussed in the context of the 2-period model, we explore two channels, one operating through income smoothing and the second one through default incentives, which ultimately affect borrowing costs. The latter channel can already be appreciated in Table 2.3, where we compare the stochastic steady state—defined as the average value of the corresponding variables in the long-run simulations—of the benchmark model with the one from the model without hedging. We find that the probability of default is higher in the model without hedging, 1.41

Figure 2.4: Welfare Gains, Borrowing, and Probability of Default



Source: Authors' calculations.

Note: Conditional welfare gains, $\Delta(w_t, p_t)$; borrowing, b_{t+1}; the probability of default in the current period; and the probability of default in the next period are plotted against values of wealth, w_t with p_t set equal to its unconditional mean.

percent versus 1.27 percent, default spreads are also higher, 1.59 percent versus 1.4 percent, and the debt level is lower, 10.50 percent versus 11.97 percent. Recall that proposition 5 implied that the impact of hedging on the debt level was ambiguous; however, our quantitative results suggest that debt increases with hedging. It increases due to a lower borrowing cost and also a stronger incentive to borrow because of the additional borrowing needed to purchase the put options.

Table 2.3: Stochastic Steady State in the Hedging and No-hedging Economies

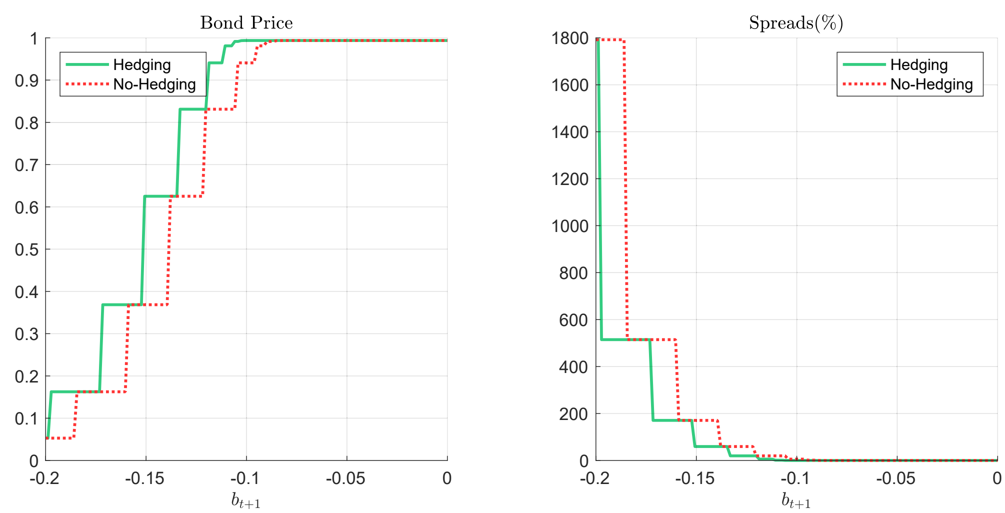
Economy	debt ratio	default spreads	default probability
Hedging	11.97 %	1.40 %	1.27 %
No-Hedging	10.50 %	1.59 %	1.41 %

Source: Authors' calculations.

Note: We run 100 Monte Carlo simulations of 2,000 periods each for the economies with and without hedging. The initial 500 periods are dropped for each simulation. The reported debt ratio and spreads are calculated as the average values, across periods and simulations, conditional on no default for each economy. The probability of default is calculated as the average fraction, across periods and simulations, of default periods.

Figure 2.5 shows bond prices and risk spreads and highlights that the model with hedging has systematically higher bond prices, except in the region where default risk is zero in which case bond prices equal 1 for both the benchmark and the no-hedging model. To decompose more explicitly the borrowing cost and income-smoothing channels of welfare gains, we solve the model without hedging after imposing the same bond price that emerges in the economy with hedging. Note that now we have two versions of the no-hedging economy. One that is solved as if bond prices were the same as if hedging was present, and the standard one where bond prices correspond to the no-hedging world. Since the only difference between these two models is the borrowing cost, the resulting welfare gains stem entirely from the borrowing costs channel.[13] Our simulation suggests that the unconditional welfare gains from the no-hedging economy with hedging bond prices relative to the no-hedging economy with no-hedging bond prices are equivalent to a permanent increase in consumption of 0.40 percent, that is, a 90 percent of the total welfare gains.

Figure 2.5: Bond Price and Sovereign Spreads



Source: Authors' calculations.

Note: Bond prices, q_t, and spreads are plotted as a function of w_t, with p_t set equal to its unconditional mean. Spreads are computed as the difference between bond yields and the international risk free rate, $100\left(\frac{1}{q_t} - 1 - r^*\right)$.

[13]The remaining channel should include gains from income smoothing, net of the cost of hedging, because the above exercise does not take into account the cost of hedging.

To gain further intuition, we examine the dynamic behavior of key variables around default episodes in Figure 2.6. To this end, we construct a 11,000-period simulation for the hedging and no-hedging economies. After dropping the first 1,000 periods, we identify all default episodes by the no-hedging economy in the remaining 10,000 periods. We look at a 20-period window, centered on the default year, that is, 10 years before and after default, and examine the evolution of key variables within this window. In Figure 2.6, we plot the average path of the corresponding variable for the hedging and no-hedging economy, keeping in mind that the hedging economy may not have defaulted.

A sharp decline in oil prices, p_t, at time 0, triggers a payoff from the options which compensates the income fall in the hedging economy. The no-hedging economy defaults, which reduces the stock of debt to zero, but the probability of default rises sharply even in the hedging economy, peaking at 89 percent. The high persistence in the oil price process keeps income prospects weak for some time in both economies, with borrowing being restored gradually, more so in the no-hedging economy than in the hedging economy. This result is the consequence of the temporary exclusion from financial markets and the higher borrowing costs for the no-hedging economy. Finally, the hedging economy is able to sustain higher levels of consumption than in the no-hedging economy, despite the cost of the options, because of lower cost of debt.

2.5.3 Robustness Check

Cost of Put Options. Our baseline calculation assumes an actuarially fair price for put options. In practice, the actual price can include a premium above the actuarially fair price. This premium may stem from non-competitive behavior, regulatory constraints, risk aversion, and market illiquidity. In the case of Mexico, the use of over-the-counter options with Maya oil as underlying asset could lead to a cost premium given that such instruments are not as liquid as options on the Brent or the West Texas Intermediate (WTI).[14] To examine the implications of such a cost premium, we now assume that there is an additional cost x per barrel of oil, above the actuarially fair price. In Figure 2.7, we plot the welfare gains from hedging against various levels of the cost premium x, expressed as a ratio to the actuarially fair price. Not surprisingly, the welfare gains decline with x; however, reducing the welfare gains to zero in this model would require a sizable premium, in the order of 2.3 times the actuarially fair price.[15] The reason for the decline in welfare gains is that the options become relatively more expensive than debt, assuming that debt remains fairly priced. Naturally, if a cost premium also affects the price of debt, then the impact on welfare gains would depend on the relative size of the distortions in debt and option prices.

[14] Mexico's decision to use Maya oil as underlying asset is justified on the grounds of avoiding base risk, defined as unexpected movements in Maya oil price not explained by movements in the price of Brent or WTI oil.

[15] The cost premium at which welfare gains are zero, expressed in 2009 constant dollars, is equivalent to US$2.1 per barrel. During 2006-2016, Mexico paid on average US$ 3.5 per barrel to purchase the put options, which is an alternative way to corroborate that the cost premium has to be sizable to reduce welfare gains to zero.

Strike Prices. In our benchmark analysis, the strike price is a fraction μ of the expected oil price for next year conditional on the current period's price. We noted in the calibration section that we could compute μ directly in the data, although for only a handful of years for which there was publicly available information. The data suggested a range for μ between 0.72 and 1.14, as shown in Table 2.1. We arbitrarily chose values for μ of 0.74 and 1.03 and solve the model again to compute the welfare gains. We found that welfare gains increase with the strike price. Moreover, as welfare gains increase, the cost premium computed above also becomes larger, suggesting that the gains becomes less sensitive to the presence of a cost premium in the price of the options. These results, and those described in the remaining of this section, are reported in Table 2.4.

Oil Price Process. Three parameters govern the oil price process, i.e. persistence ρ, volatility σ and the unconditional mean p. Increasing the unconditional mean for the oil price is inconsequential for our results if volatility and persistence remain the same. This result is intuitive since the exercise leaves risk intact. Increasing the persistence of oil prices reduces welfare gains because, given the one-year horizon of the options, hedging would compensate for a smaller fraction of the cumulative income loss relative to a scenario where oil prices recover more quickly. In turn, the welfare gains increase with the volatility of oil prices, which is associated with higher risk of

Table 2.4: Sensitivity Analysis

	Welfare Gains (%)	Debt (%)		Default Spreads (%)		Default Prob. (%)		Cost Premium
	Overall	Hedging	No Hedging	Hedging	No Hedging	Hedging	No Hedging	Hedging
baseline	0.44	11.97	10.50	1.40	1.59	1.27	1.41	2.10
$\mu = 0.74$	0.30	11.71	10.50	1.41	1.59	1.28	1.41	1.74
$\mu = 1.03$	0.75	13.47	10.50	0.94	1.59	0.90	1.41	3.74
$\alpha = 0.23$	0.31	11.52	10.50	1.41	1.59	1.27	1.41	2.10
$\alpha = 0.39$	0.65	12.29	10.50	1.01	1.59	0.96	1.41	2.13
$\rho = 0.8$	0.21	6.85	6.23	3.37	3.75	2.54	2.75	1.32
$\rho = 0.9$	0.03	2.91	3.69	7.29	16.01	3.54	5.81	0.48
$\sigma = 0.1$	-0.00	18.46	18.46	0.80	0.80	0.79	0.79	N.A.
$\sigma = 0.4$	0.37	4.28	2.20	0.12	2.71	0.15	2.07	3.03
$p = 50$	0.44	11.97	10.50	1.40	1.59	1.27	1.41	1.93
$p = 70$	0.44	11.97	10.50	1.40	1.59	1.27	1.41	2.92
$r^* = 2\%$	0.29	9.69	8.81	1.43	1.97	1.28	1.66	2.13
$r^* = 4\%$	0.17	7.92	7.37	1.50	2.26	1.31	1.82	1.75
$\gamma = 3$	0.55	11.64	10.15	1.24	1.71	1.13	1.51	2.24
$\gamma = 4$	0.74	11.70	9.55	1.24	1.75	1.14	1.53	2.42
$\lambda = 0.2$	0.17	5.30	5.36	2.62	4.85	2.29	3.80	2.10
$\lambda = 0.3$	0.04	3.58	4.10	4.54	10.18	3.79	6.93	0.54
$y^* = 0.97E[y]$	0.69	27.97	25.95	0.72	0.95	0.72	0.92	2.21
$y^* = 0.99E[y]$	0.35	5.26	4.05	0.76	2.17	0.73	1.83	2.01
$y^* = 1.05E[y]$	-0.00	0.30	0.00	283.55	4.29	10.53	1.14	N.A.
$G = 1$	0.22	8.22	7.59	1.47	1.94	1.33	1.64	1.93
$G = 1.04$	0.67	14.03	12.20	0.90	1.46	0.87	1.32	2.13
$\beta = 0.9$	0.23	15.56	14.33	0.36	0.48	0.40	0.53	1.70
$\beta = 0.98$	0.08	17.79	16.92	0.13	0.19	0.17	0.23	1.17

Source: Authors' calculations.

Note: We run 100 Monte Carlo simulations of 2,000 periods each for the economies with and without hedging. The initial 500 periods are dropped for each simulation. The reported debt ratio and spreads are calculated as the average values, across periods and simulations, excluding default episodes for each economy. The probability of default is calculated as the average fraction, across periods and simulations, of default periods. Welfare gains are calculated by constructing simulations for both economies subject to the same stochastic shocks and initial conditions, and then computing the present discounted value of the utility of consumption to ultimately express the difference in terms of consumption equivalents. Cost premium refers to the cost of options above the actuarially fair price such that the welfare gains from hedging are zero.

default, because the borrowing costs channel strengthens. Note that when welfare gains become larger, the cost premium at which gains vanish becomes larger, suggesting as before that the gains become more robust to the presence of a cost premium.

Other Parameters. We also conduct robustness checks with respect to other parameters in our model, with the results also summarized in Table 2.4. Generally speaking, the benefits from hedging are robust to different parameter values. In particular, the welfare gains are larger when a larger volume of oil production, α, is hedged because a larger fraction of income is protected. Moreover, risk spreads decline as the risk of default is lower. Gains are also larger when consumers are more risk averse, i.e. higher γ, since they dislike income fluctuations more. Welfare gains also increase with G since higher growth in non-oil income increases the desire to borrow, whose cost is reduced by hedging. Welfare gains decline when the international risk-free rate, r^*, increases, which in turns makes borrowing more expensive, reducing the desire to borrow. With lower borrowing, the benefits of hedging through the borrowing cost channel weaken. Welfare gains also decline when the income loss from default is lower. This is represented in the Table by increasing y^*. The result is analogous to what happens in the right regions of Figure 2.3 depicting the outcomes from our two-period model. Note n Table 2.4 that for sufficiently low cost of default, i.e. sufficiently high y^*, the welfare gains vanish since hedging in those cases increase default incentives (Proposition 5). Welfare gains decrease with the probability of redemption

λ. Since losing access to international financial markets is one component of the cost of default, increasing λ is equivalent to reducing the cost of default; therefore, the result is consistent with what happens when y^* is higher. Intuitively, when default is less costly, the benefits of hedging decline in the presence of defaultable debt, which serves also as a hedging and consumption smoothing instrument. Welfare gains decline with the discount factor, β, since the more patient consumers become, the less they borrow, and the weaker the borrowing costs channel of welfare gains.

2.6 Extensions

2.6.1 Selling Oil Forward

In our baseline model, the upfront cost of options generates a tradeoff. On the one hand, hedging helps smooth income, but on the other it implies devoting resources in the current period to the cost of hedging. We contrast the welfare gains with an alternative hedging vehicle: selling oil forward at a predetermined price. There is no upfront cost of insurance, as it is the case for the options, but the country also gives up any revenue windfall if oil prices rise unexpectedly. We maintain the one-year horizon of the hedge. We model this variant of hedging by assuming that the country sells a fraction α of oil production at the conditional mean of the oil price in each period. The new budget constraint and dynamics of beginning-period-of wealth are given by

$$w_t = c_t + q_t G b_{t+1}$$

$$w_{t+1} = 1 + \mathcal{Q}\left\{(1-\alpha)p_{t+1} + \alpha E_t[p_{t+1}]\right\} + b_{t+1}$$

To understand the benefits/costs of forward, we first modify our two-period model to include forwards and derive the following proposition:

Proposition 6. *Forwards and default incentives*

Define y^{def} as the income under default in the no-hedging economy such that the economy does not default when $y^{def} < \hat{y}^{def}$, i.e when the cost of default is sufficiently high. Introducing forwards at a price equal to the conditional mean increases $\hat{y}^{def}$.

Proof. Proof is given in Appendix B.2.4. □

One implication from Proposition 6 is that the introduction of forwards can reduce default incentives. A similar plot to Figure 2.3 is presented in Figure B.1[16] in the appendix. Similar to options, if default never happens, hedging through forwards increases welfare only through the income smoothing channel (Region A in Figure B.1), when the no-hedging economy defaults in the low-income state of the world, introducing forwards reduce the likelihood of default to zero since income is locked in at a level above the income level under default. In in this case, forwards increase

[16] The figure shows the case where $\hat{y}^{def,forward} < \hat{\hat{y}}^{def}$. However, it is theoretically possible that $\hat{y}^{def,forward} > \hat{\hat{y}}^{def}$.

welfare through income smoothing and lower borrowing costs (Region B in Figure B.1). For completeness, we also describe the implications of the model when default costs are sufficiently low, meaning that $y^H > \hat{\hat{y}}^{def} > \hat{y}^{def,forward} > \hat{y}^{def} > y^L$. In this case, forwards worsen default incentives. However, it is not an interesting case to examine since it would imply locking in through forwards a level of income below what the economy would get if it defaulted.

Turning now to the quantitative analysis, we find welfare gains from hedging through forwards equivalent to a permanent increase in consumption of 0.89 percent, roughly twice as large as those from our baseline model. However, recall that in our baseline calibration, the strike price for the put options is set at $\bar{p}_t = \mu E_t[p_{t+1}|p_t]$, with $\mu = 0.77$, while in this section, the economy hedges through selling oil forward at a price equal to $E_t[p_{t+1}|p_t]$. Therefore, to conduct a more appropriate comparison between forwards and options, we compute the welfare gains from hedging through put options after setting $\mu = 1$. As shown in Table 2.5, the resulting welfare gains from options are equivalent to a permanent increase in consumption of 0.75, higher than in the baseline calibration, but still below those from forwards. With forwards, the probability of default and risk spreads are lower than in the model with options, while the economy can afford to borrow more (Table 2.5).

Table 2.5: Welfare Gains from Selling Oil Forward

	Welfare Gains (%)	Debt (%)		Default Spreads (%)		Default Prob. (%)	
	Overall	Hedging	No Hedging	Hedging	No Hedging	Hedging	No Hedging
Forwards ($\mu = 1$)	0.89	14.19	10.50	0.96	1.59	0.92	1.41
Put Options ($\mu = 1$)	0.75	13.32	10.50	1.14	1.59	1.06	1.41

Source: Authors' calculations.

Note: We run 100 Monte Carlo simulations of 2,000 periods each for the economies with and without hedging. The initial 500 periods are dropped for each simulation. The reported debt ratio and spreads are calculated as the average values, across periods and simulations, excluding default episodes for each economy. The probability of default is calculated as the average fraction, across periods and simulations, of default periods. Welfare gains are calculated by constructing simulations for both economies subject to the same stochastic shocks and initial conditions, and then computing the present discounted value of the utility of consumption to ultimately express the difference in terms of consumption equivalents.

2.6.2 Risk Averse Investors

This last extension is intended to understand the benefits of hedging in a world in which global changes in risk appetite affect commodity and other asset prices simultaneously. For simplicity, we model this situation as having risk averse international investors who have a time-variant pricing kernel m_t, i.e. the intertemporal marginal rate of substitution. We follow Arellano (2008) in assuming that m_t is an i.i.d. random variable. The pricing of sovereign bond and options are given by the following formula.

$$q_t(b_{t+1}, p_t) = E_t[m_{t+1}(1 - D(y_{t+1} + b_{t+1}, p_{t+1}))] \tag{2.15}$$

$$\xi_t(p_t) = E_t[m_{t+1} \max(\bar{p} - p_{t+1}, 0)] \tag{2.16}$$

with $m_{t+1} = e^{-r^*}e^{-\nu\varepsilon_{t+1}}$ to ensure m_{t+1} is non-negative. After taking logs m_t can be written as

$$\log m_t = -r^* - \nu\varepsilon_t$$

with $E[\log m_t] = -r^*$ and $var(\log m_t) = \nu^2\sigma^2$. Note that ε_t is the same shock to oil prices, which implies that foreign investors become effectively more or less risk averse when oil prices decrease or increase. We solve the model and compute the welfare gains using the same procedures as before but subject to the above pricing equations. In Table 2.6 we report the results for various values of ν. Risk aversion implies foreign investors demand a premium above the spread necessary to compensate default risk, making debt more expensive and discouraging borrowing. But foreign investors also demand an extra compensation for risk when selling put options, making the options also more expensive. However, hedging has now an extra channel through which it could increase welfare, through its effect on the risk premium demanded by foreign investors, which depends on the risk of default. Our quantitative analysis in Table 2.6 suggests that the welfare gains are larger as foreign investors become more risk averse, i.e. ν increases, despite the higher upfront cost of insurance.

Table 2.6: Risk Averse Investors: Hedging and No-hedging Economies

	Welfare Gains (%)	Debt (%)		Default Spreads (%)		Default Prob. (%)		Cost Premium
	Overall	Hedging	No Hedging	Hedging	No Hedging	Hedging	No Hedging	Hedging
$\nu = 0$	0.44	11.97	10.50	1.40	1.59	1.27	1.41	2.52
$\nu = 0.25$	0.44	11.77	10.59	1.24	1.89	0.86	1.30	2.10
$\nu = 0.5$	0.59	13.03	11.35	1.45	2.42	0.50	1.10	2.06
$\nu = 0.75$	0.98	17.82	14.15	2.20	2.44	0.32	0.46	2.08

Source: Authors' calculations.

Note: We run 100 Monte Carlo simulations of 2,000 periods each for the economies with and without hedging. The initial 500 periods are dropped for each simulation. The reported debt ratio and spreads are calculated as the average values, across periods and simulations, excluding default episodes for each economy. The probability of default is calculated as the average fraction, across periods and simulations, of default periods. Welfare gains are calculated by constructing simulations for both economies subject to the same stochastic shocks and initial conditions, and then computing the present discounted value of the utility of consumption to ultimately express the difference in terms of consumption equivalents.

2.7 Conclusion

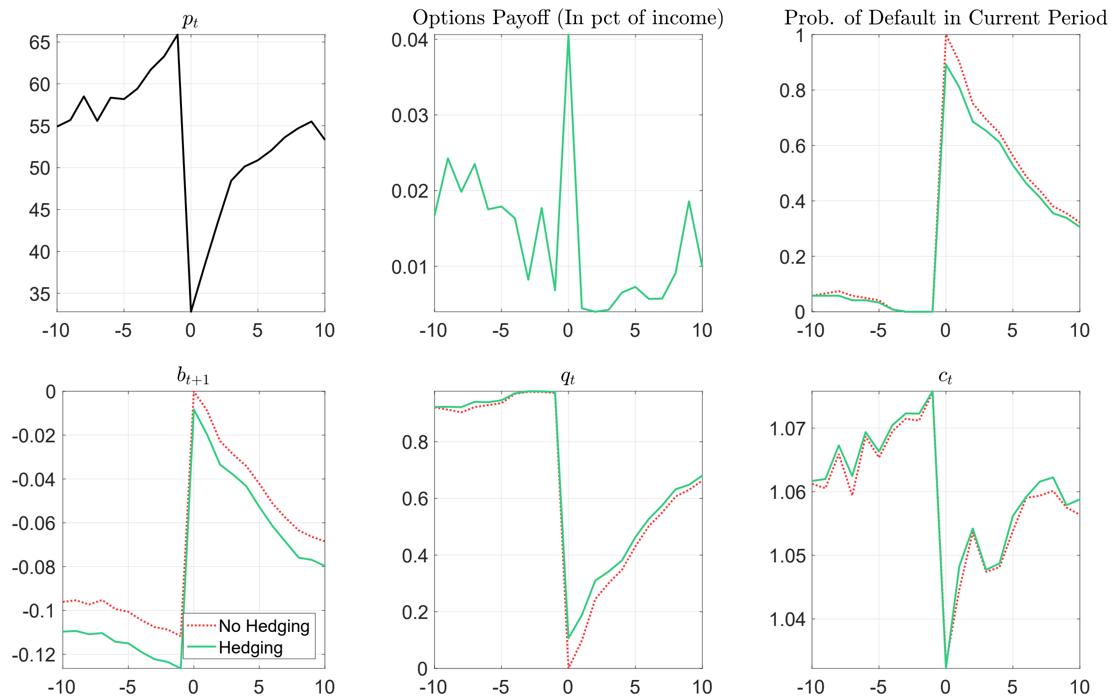
The sharp unexpected decline in oil prices during 2014-2016 renewed the interest in designing policies to manage such risks in countries highly exposed to swings in commodity prices. Discussions about the various alternatives to countries often start with Mexico, given its longstanding practice of hedging through put options, but analyses of the welfare gains of such policy have been limited. This paper attempts to fill this gap and derives lessons about the benefits and costs for commodity exporters of using market insurance to hedge commodity price risk.

We have focused our analysis on the role of hedging instruments as a complement to defaultable debt, which in and on itself can be seen as a hedging strategy. Our quantitative assessment concludes that the welfare gains from hedging, in the presence of defaultable debt, can be equivalent to a permanent increase in consumption of about 0.44 percent. We also find that about 90 percent of these gains stem from a reduction in borrowing costs and the difference from income smoothing. The beneficial role of hedging is robust to numerous sensitivity analyses.

In terms of lessons for the design of a program like Mexico's, the welfare gains are lower when option prices exceed their actuarially fair value, a circumstance that may become more likely when using relatively illiquid, over-the-counter options. It may then be worth accepting some base risk to ensure hedging is welfare enhancing. Nevertheless, the model suggests that the premium above the actuarially fair price would have to be very large for the welfare gains to decline to zero.

The model also suggests that selling oil forward generates larger welfare gains than hedging through put options. However, political economy considerations cannot be ignored since selling oil forward implies giving up any potential revenue windfall if oil prices rise. Mexico, through the use of options, seems to have found a good balance between these political economy constraints and the benefits of market instruments to hedge oil price risk.

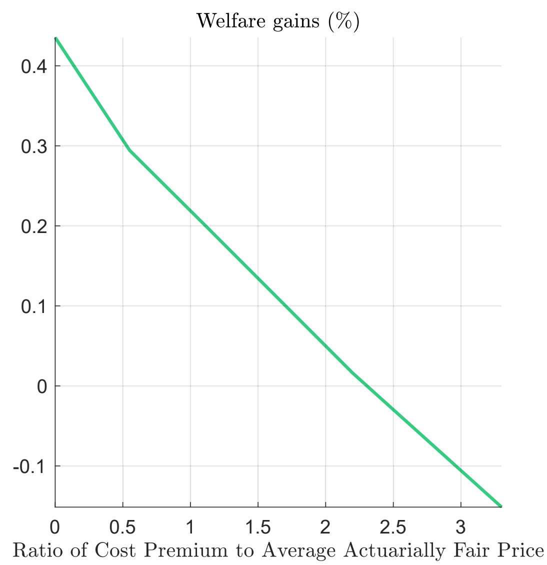
Figure 2.6: Event Windows



Source: Authors' calculations.

Note: The event windows are selected by first running an 11,000-period simulation for the hedging and no-hedging economies. After dropping the first 1,000 periods, we identify all default episodes by the no-hedging economy in the remaining 10,000 periods and compute the average evolution of the selected variables depicted in the charts.

Figure 2.7: Welfare Gains under Different Cost Premiums



Source: Authors' calculations.

Note: Unconditional welfare gains as a function of the cost premium x, expressed as a ratio to the actuarially fair price.

Chapter 3

Self-Regulation Versus Government Regulation: An Externality View

"As I have stated before, it is the private sector, not the public sector, that is in the best position to provide effective supervision."[1]

— Larry Summers in 2000

"No substantially interconnected institution or market on which the system depends should be free from rigorous public scrutiny."[2]

— Larry Summers in 2009

[1] See "Remarks of Treasury Secretary Lawrence H. Summers to the Securities Industry Association" on Nov. 9, 2000 at `http://www.treasury.gov/press-center/press-releases/Pages/ls1005.aspx`.

[2] See "Remarks of Lawrence H. Summers Director of the National Economic Council Responding to an Historic Economic Crisis: The Obama Program" on March 13, 2009 at `https://www.brookings.edu/wp-content/uploads/2012/04/0313_summers_remarks.pdf`.

3.1 Introduction

Self-regulation has been a feature for many industries and professions throughout the world. In the U.S. financial markets, all firms dealing with securities are required to be members in one of two self-regulatory organizations (SROs): Financial Industry Regulatory Authority (FINRA) or the Municipal Securities Rulemaking Board. These SROs license their members, write and examine rules for market players, and are themselves also subject to government regulation.[3] Self-regulation is not a unique feature for security markets but also exists in other industries such as the nuclear and chemical industry. Interestingly, a similar arrangement is prevalent in many professions such as accounting, law and medicine. Moreover, self-regulation is a worldwide phenomenon. For example, the Swiss Banker Association plays an important role in implementing banking regulation in Switzerland, and the Advertising Standards Authority conducts regulation in the UK advertising industry.

The existence of self-regulation has confused many people for a long time due to the conventional belief that a private organization can never achieve efficient and effective market discipline given its internal conflict of interest. From the quotes at the beginning of the introduction, it is not hard to see the stark difference between Larry Summers before and after the Great Recession, where he discusses how to allocate the regulatory power between the private and public sector. Indeed, the

[3] For a detailed description for FINRA, see `http://en.wikipedia.org/wiki/Financial_Industry_Regulatory_Authority`.

allocation of regulatory power between an SRO and government has significant welfare implications. Given its widespread popularity in different industries, one might expect a comprehensive understanding of self-regulation versus government regulation in the literature. However, some fundamental questions are still unclear. For example, what is the trade-off between industrial self-regulation and government regulation? What is the optimal regulatory mechanism when regulating an industry? In this paper, I provide a simple theoretical framework to understand these questions.

Broadly speaking, self-regulation refers to the phenomenon in which an industry establishes a private organization to exercise regulatory authority over the industry members. Obviously, the effectiveness of self-regulation depends on whether the government grants an SRO regulatory power. In some industries, the government delegates regulatory power to private sectors, such as FINRA in the securities market. In other industries, however, the government still controls regulatory power, but the SRO significantly affects industry regulation, such as the Institute of Nuclear Power Operation in the nuclear industry and the American Medical Association in the medical profession. These are typical examples of regulatory capture. In either case, self-regulation can be conducted in an effective way and can shape the industry's regulatory policy. In this paper, I refer to self-regulation as cases where an SRO has de facto regulation over the industry.

There are many explanations for the emergence of self-regulation, such as asymmetric information, externalities, forestalling public intervention, moral concerns, etc.

CHAPTER 3. SELF-REGULATION VERSUS GOVERNMENT REGULATION: AN EXTERNALITY VIEW

In this paper, I take an externality view and analyze the scope of self-regulation in addressing market inefficiencies in the economy. By introducing a simple general theoretical framework, I investigate the trade-off between self-regulation and government regulation. In the end, I also analyze the optimal regulatory mechanism and apply theoretical insights to real-world observations and ongoing policy debates.

In the model, there are three elements affecting the trade-off between self-regulation and government regulation. The first element is about the externalities in the economy. Depending on who is affected, the different types of externalities make a large difference. An SRO has an incentive to internalize any externalities within the industry but has no incentive to internalize externalities to the rest of society. Even worse, the SRO's behavior might exacerbate such externalities to society. The government, on the other hand, has an incentive to correct any types of externalities. The second element is about monopoly distortions. Self-regulation is usually associated with monopoly power since an SRO can coordinate industry behavior through regulation. The last element is about asymmetric information. Government regulation can correct any externalities if the government has perfect information about the economy. The existence of asymmetric information between the public and private sector renders the effectiveness of government regulation and thus creates a role for self-regulation.

To fully understand this trade-off, I impose more informational structure and apply a second-order approximation following Weitzman (1974) and Laffont (1977).

I find that self-regulation is more desirable than government regulation if the degree of asymmetric information is larger than the size of monopoly distortion and the externalities to society. Moreover, not all information asymmetries matter for this trade-off. In particular, the asymmetric information about the externalities to the rest of society does not matter as long as it is uncorrelated with the asymmetric information about other externalities. The intuition is as follows. An SRO has no incentive to utilize information on the externalities to the rest of society for the regulation on its own industry. Even if the government has an incentive to correct such externalities, the regulation is not effective due to the asymmetric information issue. As a result, asymmetric information does not affect the trade-off between self-regulation and government regulation.

I also derive an optimal regulatory mechanism in this economy. The general message is to combine both self-regulation and government regulation where self-regulation aims at correcting externalities within the sector, and government regulation aims at correcting any distortions from self-regulation. Depending on the information structure of the government, the first best allocation might not be implementable. In particular, if the government does not have information about the externalities to society, the first best can never be achieved since an SRO has no incentive to utilize such information. But a second best allocation can be achieved as long as the government has enough information to correct the monopolistic distortions generated by the SRO.

The insights of the general framework can be applied to many empirical observations and theoretical works. I provide several arguments to apply this insight in order to understand regulatory arrangements in many different industries. I argue that the degree of the three elements identified in this paper plays an important role. Furthermore, their relative importance can change with the development of industries. Moreover, the insights can be applied to many policy discussions. I argue that there should be a room for self-regulation other than government regulation.

Literature Review This paper is related to several strands of literature. In particular, it is related to the literature on industrial self-regulation.[4] Existing work has focused on the reasons that firms want to join the SROs for self-regulation in different industries. For example, King et al. (2011) provides an excellent survey of the adoption of industry self-regulation. Maxwell et al. (2000) provides both a theoretical and empirical work to argue that firms form self-regulation to preempt government regulations. Lyon and Maxwell (2003) and Lyon and Maxwell (2012) analyze the welfare implication of self-regulation with the interaction of government. Departing from this literature, this paper takes an externality view and focuses on the scope of self-regulation.

This paper is also related to the literature investigating the benefits and costs of self-regulation. There is evidence that self-regulation tends to generate monopolistic distorations. For example, Shaked and Sutton (1981) argue that a professional group

[4]For example, there are many theoretical work on self-regulation in financial markets including Núñez (2001), Stefanadis (2003), DeMarzo et al. (2005), Núñez (2007) and Aboura and Lepinette (2014), etc.

tends to restrict the number of members to gain monopoly power. Moreover, Pirrong (1995) argues that self-regulation is a weak tool to prevent monopoly power by analyzing the self-regulation of commodity exchanges. There is some evidence that an SRO tends to behave in favor of the industry rather than consumers (see DeMarzo et al. (2005)). Even so, there are still benefits for the existence of self-regulation. For example, Carson (2011) argues that self-regulation is important for emerging markets to develop financial markets. Leland (1979), Gehrig and Jost (1995) and Shapiro (1986) model the economic benefit of self-regulation as reducing asymmetric information and argue that its existence might improve the welfare of society. This paper provides a general framework to analyze the trade-off between self-regulation and government regulation.[5] Consistent with the literature, I argue that government regulation improves the effectiveness of self-regulation. For example, Kondo (2007) provides evidence that more control of an SRO over customer–firm dispute resolution increases the level of enforcement against a firm's misbehavior. Moreover, DeMarzo et al. (2005) show that government oversight is desirable to reduce the misbehavior of the SRO.

The organization of the paper is as follows: Section 3.2 presents the general model; Section 3.3 derives an optimal regulatory mechanism; Section 3.4 provides several applications; and Section 3.5 concludes.

[5]Grajzl and Murrell (2007) also pursue the question of self-regulation versus government as an allocation of lawmaking power and identify conditions for improving social welfare. However, my work is more general than theirs and can be applied to other fields other than lawmaking as well.

3.2 The Model

In this section, I provide a simple general framework to analyze the scope of self-regulation and government regulation.

3.2.1 Environment

The economy consists of two sectors: producers and consumers, where each sector has a continuum of individual agents. There is only one good in the economy, which is traded at a market price p. There is a case for regulation in this economy due to the existence of externalities.[6] It is assumed that there are two types of externalities, which are generated by producers and negatively affect both producers and consumers. Hence, there is a case for industrial self-regulation to internalize externalities within the producer sector. There is also room for government regulation because producers have no incentive to internalize the externalities affecting consumers.

Producers There is a continuum of producers indexed by $i \in [0, 1]$. Producer i produces good x_i at a cost of $c(x_i; \theta)$, where x_i denotes the quantity of the good and θ summarizes all the parameters in the cost function. Moreover, there is a general equilibrium effect on individual profit captured by the term $C(X; \Theta)$, where $X = \int x_i di$ is the overall production of the good and Θ is the parameter. This general

[6] To simplify analysis, I do not provide a micro-foundation for such externalities. In the applications, I provide examples to illustrate how such externalities might evolve.

equilibrium effet is a negative externality from production, which hurts the producer sector. One rationale is the existence of a production externality: excessive production leads to a reduction of profit for individual production. Presumably, $c' > 0, C' > 0$ and $c'' > 0, C'' > 0$ are imposed. The profit Π^i for individual producer i is given by

$$\Pi^i = px_i - c(x_i; \theta) - C(X; \Theta)$$

Consumers There is a continuum of consumers indexed by $j \in [0, 1]$. Consumer j buys consumption good y_j from producers at price p. Moreover, the consumer's utility function takes the form of $u(y_j; \phi)$, where y_j is the individual demand of consumer j and ϕ is the parameter. Similarly, there is an additional term $U(X; \Phi)$ rationalized as consumption externalities where Φ summarizes the parameters. It is assumed that $u' > 0, U' > 0$ and $u'' < 0, U'' > 0$. The utility U^j for consumer j is given by

$$U^j = u(y_j; \phi) - py_j - U(X; \Phi)$$

Competitive Equilibrium consists of an allocation (x_i^{CE}, y_j^{CE}) and price p such that under price p, x_i^{CE} maximizes Π^i and y_j^{CE} maximizes U^j for $\forall i, j \in [0, 1]$. Moreover, the market clears, i.e., $X^{CE} = \int_0^1 x_i^{CE} di = Y^{CE} = \int_0^1 y_j^{CE} dj$.

Given the definition of competitive equilibrium, one can solve the optimality condition for X^{CE}, which satisfies

$$u'(X^{CE};\phi) = c'(X^{CE};\theta) \tag{3.1}$$

First Best Allocation Unsurprisingly, the allocation under competitive equilibrium is not socially optimal given the existence of externalities in the economy. To formalize the idea, we define the first best allocation as the one chosen by a utilitarian social planner who cares equally about consumers and producers. As is noted later, such an allocation should be considered as the first best allocation since there is no asymmetric information between the social planner and private agents. The social planner can improve the collective welfare of consumers and producers by internalizing both the technology externality and consumption externality. The planner's optimization problem is given as follows:

$$\max_X u(X;\phi) - U(X;\Phi) - c(X;\theta) - C(X;\Theta)$$

The optimality condition for the social optimal allocation X^{FB} satisfies

$$u'\left(X^{FB};\phi\right) = U'(X^{FB};\Phi) + c'(X^{FB};\theta) + C'(X^{FB};\theta) \tag{3.2}$$

Inefficiency of Competitive Equilibrium By comparing the optimality conditions (3.1) and (3.2), it is not hard to see that $X^{CE} > X^{FB}$ since $U', C' > 0$. In other words, there is an over-production in competitive equilibrium. This result is straightforward since both producers and consumers fail to internalize the externality terms.[7]

Implementation of First Best Allocation Intuitively, implementation of the first best allocation requires a knowledge of all the parameters such as $\{\theta, \Theta, \phi, \Phi\}$. As we will show later, all the government needs to know is the information about the consumer side, $\{\phi, \Phi\}$. By joining with an industrial self-regulatory organization, the first best allocation can be implemented.

3.2.2 Government Regulation and Industrial Self-Regulation

Regulation is justified since there is a discrepancy between competitive equilibrium and the first best allocation. The interesting question is who should conduct regulation: an SRO representing producers or a government representing both consumers and producers. As discussed before, the SRO has an incentive to internalize the externalities within the producer sector but not the externalities to the consumers.

[7]It is the producers who should bear the blame for over-production because the externality term depends on total production by assumption. However, total production equals total consumption in equilibrium. Furthermore, it is possible that consumers are also responsible for the inefficiency if the externality term depends on total consumption.

Moreover, it generates monopolistic distortions.[8] Hence, government regulation is needed to address such concerns. However, there might be an asymmetric information issue for the government. It is reasonable to assume that producers have a better information structure than the government. Specifically, we assume that producers can perfectly observe the information structure $\mathcal{F} = \{\theta, \Theta, \phi, \Phi\}$, while the government cannot observe all of them. Instead, the government has a prior distribution over $\mathcal{F}$. Hence, there is a trade-off between government regulation and self-regulation.

Lemma 1. ***Government Regulation***

A benevolent government chooses allocation $X^G < X^{CE}$ to maximize expected social welfare. To implement X^G, it can put restrictions on individual production x_i.

Proof. See Appendix C.1.1. □

A brief comparison between the first best allocation X^{FB} and the allocation under government regulation X^G reveals the inferior information structure of government. Ex ante, X^G implements X^{FB} based on the government's information structure. Ex post, there is some discrepancy since X^{FB} is a function of parameters in $\mathcal{F}$ while X^G is constant. This difference captures two types of cost for government regulation in reality. First, government regulation suffers from asymmetric information. The inability of precisely targeting the source of externalities becomes a distortion for government

[8]Indeed, correcting externalities to consumers requires a reduction in production, the same result when the SRO exerts monopolistic distortion. However, the magnitude of reduction in production might differ. Furthermore, depending on assumptions, correcting externalities to consumers might call for an increase in production.

regulation. Second, even if the government has the same information structure as the private sector, government regulation is inflexible to changing parameters due to many other restrictions, such as budget constraints, political processes, etc.

An SRO plays a role in regulation since it has a superior information structure. But it also has two types of costs due to the incentive problem. Since an SRO has the power to set rules in coordinating industry-level production, it can effectively introduce monopoly power in many respects, such as choosing an industry standard to restrict supply as in Leland (1979) and Shaked and Sutton (1981). Here, I simply model the monopoly distortion by assuming that an SRO can perfectly observe a downward-sloping demand curve defined by $p(X;\phi) = u'(X;\phi)$. Furthermore, the SRO has no incentive to internalize externalities to consumers $U(X;\Phi)$ even if they can observe the externality parameter Φ perfectly.

Lemma 2. ***Self-Regulation***

An SRO chooses industry production level $X^S < X^{CE}$ to maximize the collective profit of producers. It can implement X^S by putting production restrictions on the industry.[9]

Proof. See Appendix C.1.2 □

There is no conflict of interest between an SRO and an individual producer since the SRO and the individual producer share the same profit function. By internalizing

[9]It might seem strange to claim that an SRO could choose production level since it violates anti-trust law. But effectively, an SRO can affect individual choice of production by choosing regulation rules and achieve its ideal production level.

the production externality and pursuing monopoly rent, the profit of the industry has been increased. However, this might hurt the welfare of consumers. Specifically, there are two distortions with self-regulation: the monopoly distortion captured by the term $u''(X^S;\phi)X^S$ and the externalities to consumers captured by $U(X^S;\Theta)$.

3.2.3 Trade-off of Self-Regulation Versus Government Regulation

From the analysis in Lemma 1 and 2, neither government regulation nor self-regulation can implement the first best allocation X^{FB}. A natural question to consider is the trade-off between self-regulation and government regulation. Specifically, if one has to choose between industrial self-regulation and government regulation, what factors should be considered? To answer this question, I define the following welfare function $\Delta^{S/G}$, which measures the welfare benefit of self-regulation over government regulation under the information structure of government. Presumably, one prefers self-regulation if $\Delta^{S/G} > 0$, and government regulation otherwise.

$$
\begin{aligned}
\Delta^{S/G} &\equiv E[W(X^S;\mathcal{F}) - W(X^G;\mathcal{F})] \\
&\equiv E[u(X^S;\phi) - U(X^S;\Phi) - c(X^S;\theta) - C(X^S;\Theta)] \\
&- E[u(X^G;\phi) - U(X^G;\Phi) - c(X^G;\theta) - C(X^G;\Theta)]
\end{aligned}
$$

where the expectation is taken over the prior distribution of information structure $\mathcal{F}$.

To get an analytical solution for $\Delta^{S/G}$, I follow Weitzman (1974) and Laffont (1977) to impose information structure in the model and apply a second-order approximation. Specifically, functions u, U, c, C can be approximated around $x = X^G$ or $X = X^G$ as follows.

$$
\begin{aligned}
u(x;\phi) &\approx u\left(X^G;\phi\right) + [\bar{u'} + \phi](x - X^G) + \frac{1}{2}\bar{u''}(x - X^G)^2 \\
U(X;\Phi) &\approx U\left(X^G;\Phi\right) + [\bar{U'} + \Phi](X - X^G) + \frac{1}{2}\bar{U''}(X - X^G)^2 \\
c(x;\theta) &\approx c\left(X^G;\theta\right) + [\bar{c'} + \theta](x - X^G) + \frac{1}{2}\bar{c''}(x - X^G)^2 \\
C(X;\Theta) &\approx C\left(X^G;\Theta\right) + [\bar{C'} + \Theta](X - X^G) + \frac{1}{2}\bar{C''}(X - X^G)^2
\end{aligned}
$$

The restrictions on information structure imply that information asymmetries $\mathcal{F}$ only appear up to the first-order derivatives. To normalize, I assume the parameters have zero mean and denote their variance by $\sigma^2_{\mathcal{F}}$. Moreover, the parameters in $\mathcal{F}$ are uncorrelated.

The relative welfare benefit of self-regulation over government regulation can be approximated as

$$
\begin{aligned}
\Delta^{S/G} &\approx E\left[(\bar{u'} - \bar{U'} - \bar{c'} - \bar{C'} + \phi - \Phi - \theta - \Theta)(X^S - X^G)\right] \\
&+ \frac{1}{2}(\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''})E\left[(X^S - X^G)^2\right]
\end{aligned}
$$

Applying the optimality condition for X^S and X^G, $\Delta^{S/G}$ can be approximated by the following relationship.[10]

$$\begin{aligned}
\Delta^{S/G} &\approx E\left[(\bar{u'} - \bar{U'} - \bar{c'} - \bar{C'} + \phi - \Phi - \theta - \Theta)(X^S - X^G)\right] \\
&+ \frac{1}{2}(\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''})E\left[(X^S - X^G)^2\right] \\
&= -\frac{\sigma_\phi^2 + \sigma_\theta^2 + \sigma_\Theta^2}{\bar{u''} - \bar{c''} - \bar{C''} + \bar{u''}} + \frac{\sigma_\phi^2 + \sigma_\theta^2 + \sigma_\Theta^2}{2}\frac{\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''}}{(\bar{u''} - \bar{c''} - \bar{C''} + \bar{u''})^2} \\
&+ \frac{1}{2}\frac{\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''}}{(\bar{u''} - \bar{c''} - \bar{C''} + \bar{u''})^2}\left(\bar{u''}X^G + \bar{U'}\right)^2 \\
&= \underbrace{\Psi(\sigma_\phi^2 + \sigma_\theta^2 + \sigma_\Theta^2)\left(\frac{1}{2} + \frac{\bar{U''} + \bar{u''}}{\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''}}\right)}_{\text{Benefit of Self-Regulation}} - \underbrace{\frac{1}{2}\Psi\left(\bar{u''}X^G + \bar{U'}\right)^2}_{\text{Cost of Self-Regulation}}
\end{aligned}$$

where

$$\Psi \equiv -\frac{\bar{u''} - \bar{U''} - \bar{c''} - \bar{C''}}{(\bar{u''} - \bar{c''} - \bar{C''} + \bar{u''})^2} > 0$$

The advantage of self-regulation comes from the SRO's superior information structure. Information about ϕ, θ and Φ improves the efficiency of self-regulation over

[10] Apply the approximation for optimality conditions (C.1) and (C.2).

$$\begin{aligned}
0 &= E[u'(X^G;\phi) - U'(X^G;\Phi) - c'(X^G;\theta) - C'(X^G;\Theta)] \\
&\approx E[\bar{u'} + \phi - \bar{U'} - \Phi - \bar{c'} - \theta - \bar{C'} - \Theta] \\
&= \bar{u'} - \bar{U'} - \bar{c'} - \bar{C'}
\end{aligned}$$

$$\begin{aligned}
0 &= u'(X^S;\phi) + u''(X^S;\phi)X^S - c'(X^S;\theta) - C'(X^S;\Theta) \\
&\approx \bar{u'} + \phi + \bar{u''}X^S - \bar{c'} - \theta - \bar{C'} - \Theta + (\bar{u''} - \bar{c''} - \bar{C''})(X^S - X^G) \\
&= \bar{U'} + \phi - \theta - \Theta + \bar{u''}X^S + (\bar{u''} - \bar{c''} - \bar{C''})(X^S - X^G)
\end{aligned}$$

The difference between X^G and X^S can thus be written as

$$X^S - X^G = -\frac{\bar{u''}X^G + \bar{U'} + \phi - \theta - \Theta}{\bar{u''} - \bar{c''} - \bar{C''} + \bar{u''}}$$

government regulation. Since X^S is a function of ϕ, θ and Θ, it represents an inherent regulatory advantage of self-regulation. But superior information can also create distortions. The second component in the bracket of benefit of self-regulation, $\frac{\bar{U''}+\bar{u''}}{\bar{u''}-\bar{U''}-\bar{c''}-\bar{C''}}$ captures the distortions associated with its superior information. $\bar{U''}$ captures the externalities to consumers while $\bar{u''}$ captures the monopolistic distortion. If there is large asymmetric information about the externalities to consumers, the effectiveness of government regulation is reduced. If the monopolistic distortion is very large, captured by a large curvature of individual utility function $u(\cdot)$, it is better to use government regulation since an SRO simply uses its superior information to generate monopolistic distortion.

As noted before, there are two types of distortions with an SRO. First, the SRO has an incentive to create monopoly distortions. This is captured by two pieces: one is associated with its superior information captured by the term $\bar{u''}$ in the bracket of benefit of self-regulation, and the other is not related to information captured by the term $\bar{u''}X^G$ in the bracket of cost of self-regulation. Second, the SRO has no incentive to internalize its effect on consumers even if it has superior information about $\mathcal{F}$. The distortions are captured by $\bar{U''}$ and $\bar{U'}$ respectively in the second term of bracket in the benefit and cost of self-regulation.

There is one further interesting result from this approximation: information about Φ is irrelevant if it is not correlated with other parameters. The reason is that only the government cares about the externalities to consumers. But an SRO has no use for such information since Φ does not affect its profit function. Only if Φ could provide information about other unknown parameters will it affect the trade-off between self-regulation and government regulation.

Claim 1. ***Trade-off of Self-Regulation Versus Government Regulation***

The trade-off of self-regulation versus government regulation depends on three elements: the degree of asymmetric information, the size of monopoly distortions and the externalities to consumers. Self-regulation is more desirable if

- *degree of asymmetric information is large;*
- *size of monopoly distortions is small;*
- *size of externalities to consumers is small.*

Moreover, the asymmetric information about externalities to consumers is irrelevant for the trade-off unless it provides information about other sources of asymmetric information in the economy.

3.3 Optimal Regulatory Mechanism

I have established the trade-off between self-regulation and government regulation in the economy. One interesting question is how to utilize the benefits of both the SRO and the government and thus provide an optimal regulatory mechanism. To understand this question, we start from a case in which the government has perfect information such that the first best allocation X^{FB} can be implemented. Then we introduce the asymmetric information problem as before and analyze the optimal regulatory mechanism in this setting.

Proposition 7. ***Optimal Regulation Under Perfect Information***

If government can observe $\mathcal{F}$, it can implement the first best allocation X^{FB} using the following three mechanisms:

1. *Regulating individual consumers by a Pigovian tax $\tau = U'(X^{FB};\Phi)+C'(X^{FB};\Theta)$ that is rebated by $T = \tau X^{FB}$ or a quantity restriction $y_j \leq X^{FB}$.*

2. *Regulating individual producers by a Pigovian tax $\tau_0^* = -U'(X^{FB};\Phi)-C'(X^{FB};\Theta)$ that is rebated by $T_0^* = -\tau_0^* X^{FB}$ or a quantity restriction $x_i \leq X^{FB}$.*

3. *Regulating an SRO by a Pigovian tax $\tau_1^* = -U'(X^{FB};\Phi) - u''(X^{FB};\phi)X^{FB}$ on production that is rebated by $T_0^* = -\tau_1^* X^{FB}$.*

Moreover, if $\tau_1^* > 0$, the government can implement the first best allocation X^{FB} by delegating regulatory power to a specific number of multiple SROs.

Proof. See Appendix C.1.3 □

Proposition 7 provides a benchmark to implement the first best allocation. Clearly, there is not much room for self-regulation if the government has the same information structure as the production sector. In terms of implementation, it is equivalent to purely regulating the consumers or the producers since the demand and supply coincide in equilibrium.[11] Furthermore, there is an equivalent result between price- and quantity-based regulation, a well-known result in the literature, as in Weitzman (1974).

As for the role of self-regulation, government regulation is needed to correct any distortions generated by an SRO. Only if the monopolistic distortions generated by the SRO is larger than the externalities to consumers does there exist a specific market stucture such that the first best allocation can be implemented by the self-regulation. The intuition is straightforward. When the monopolistic distortion is large enough, one SRO tends to reduce production too excessively. The resulting equilibrium with self-regulation is under-production with respect to the first best allocation. Introducing competition between SROs increases production, which moves the equilibrium toward the first best allocation.

The question becomes more interesting once the government has limited information about $\mathcal{F}$. Intuitively, the industry knows $\mathcal{F}$ and utilizes it in its decision-making process. However, the information about Φ plays no role in an SRO's choice X^S due to a lack of incentive. Therefore, unless government has information about Φ, the first best allocation cannot be achieved. In such a scenario, one can expect that the maximum social welfare in an environment where government and an SRO cooperates

[11] One direct implication is that government can regulate both the consumers and producers to implement the first best allocation. For simplicity, Proposition 7 only considers regulations either on consumers or producers. For the analysis below, I focus on the regulations on the producer side.

is $\bar{W}$, which is a second best benchmark.

$$\bar{W} = \max_{X} u(X;\phi) - E[U(X;\Phi)] - c(X;\theta) - C(X;\Theta) \tag{3.3}$$

It is reasonable to argue that an SRO has the same incentive as the government to reduce externalities in the industry. From that perspective, information about θ and Θ can be utilized properly even if the government does not know directly. The difficulty comes from information about ϕ. An SRO has a distorted incentive to extract monopoly rent. Therefore, knowledge about ϕ determines the implementation of the second best social welfare $\bar{W}$.

Proposition 8. ***Optimal Regulation If Government Knows Demand Information*** *If the government knows demand information ϕ, the second best allocation $\bar{W}$ can be implemented. Specifically, the government announces a Pigovian tax formula $\tau(X;\phi) = -u'(X;\phi) + \frac{u(X;\phi)-E[U(X;\Phi)]}{X}$ to an SRO to replace its demand function. Meanwhile, an SRO is subsidized by a lump-sum transfer $T = -\tau(X;\phi)X$.*

Proof. See Appendix C.1.4. □

The intuition behind Proposition 8 is as follows. The SRO has an incentive to internalize the externalities within the production sector. Hence, the government does not need to know the parameters about such externalities. Instead, the SRO has no incentive to internalize the externalities to consumers, whose information asymmetry matters for the government regulation. If the government only knows the demand information ϕ, it can announce a tax schedule to correct the monopolistic distortions from the SRO and implement the second best allocation. Furthermore, if the government also knows the externality parameter Φ, the first best allocation X^{FB} can be implemented (see Corollary 1).

Corollary 1. *If the government knows demand information ϕ and externalities parameter Φ, the first best allocation X^{FB} can be implemented. Specifically, the government announces a Pigovian tax formula $\tau(X;\phi,\Phi) = -u'(X;\phi) + \frac{u(X;\phi)-U(X;\Phi)}{X}$ to an SRO to replace its demand function. Meanwhile, an SRO is subsidized by a lump-sum transfer $T = -\tau(X;\phi,\Phi)X$.*

The second best allocation cannot be implemented if the government has no information about ϕ, which delivers a similar message as in Armstrong and Sappington (2007).[12] In such scenarios, the relative social welfare function should be revised, and I define the following social welfare function $\bar{\bar{W}}$.

$$\bar{\bar{W}} = \max_X E[u(X;\phi) - U(X;\Phi)] - c(X;\theta) - C(X;\Theta)$$

Proposition 9. ***Optimal Regulation for Unknown Demand Information***

If the government does not know demand information ϕ, the second best allocation $\bar{W}$ cannot be implemented. Only $\bar{\bar{W}}$ can be implemented through price regulation.

[12] In Armstrong and Sappington (2007), they summarize the insights about regulating a monopoly and claim that the first best can be implemented if the regulator knows consumer demand. Here in my settings, if the government knows the demand parameter ϕ, it can only implement the second best since the government also needs to know the externality parameter Φ.

Specifically, the government buys goods according to a price menu where $P(X) = E[u'(X;\phi) - U'(X;\Phi)]$.

Proof. See Appendix C.1.5. □

The general message from Proposition 7, 8 and 9 can be summarized as follows. First, that optimal mechanisms consist of government regulation, which corrects monopoly distortions and externalities to consumers; and self-regulation, which corrects externalities to producers. Second, the first best allocation can be implemented if the government knows at least the information about the demand parameter ϕ and externality parameter Φ.

3.4 Applications

In this section, I provide several empirical and theoretical applications for my general framework. The goal is twofold. First, I apply the insights from the previous analysis to understand many empirical observations in the real world, especially why self-regulation is more desirable than government regulation in some industries. Second, I argue that the idea of self-regulation should be added into some ongoing policy discussions, such as banking regulation.

3.4.1 Mapping to the Real World

In the real world, many industries have self-regulations. One important question is why self-regulation emerges in some markets and whether such arrangements are socially desirable. The key insight from Claim 1 is essentially a benefit/cost analysis based on three elements: the degree of asymmetric information, the size of monopoly distortions, and the size of externalities to consumers. Whenever the degree of asymmetric information about the externalities in the industry is larger than the size of monopoly distortion and the externalities to consumers, self-regulation is superior to government regulation. To understand different regulatory mechanisms in different markets, one need to quantify these three elements. Although it is difficult to quantify all three components in the data, one can still make inferences based on subjective judgments.

For example, in the nuclear industry, the role of INPO is to set rules and standards for its members since writing such criteria requires specific knowledge and working experience. It is more efficient for the industry expert to do so, which justifies the scope for self-regulation. The monopoly distortion from the nuclear industry tends to be small since products from the nuclear industry can be perfectly substituted by products from the traditional power industry. Even if the externalities from the nuclear industry to the general public are catastrophic, the probability of such events is small and tends to be declining as technology improves. Overall analysis suggests that the benefit of self-regulation overrides the cost. Therefore, it is reasonable to have self-regulation in the nuclear industry.

Similar arguments can be applied to the securities market. The asymmetric information about the externalities between different securities firms is very large since consumers cannot perfectly observe service quality provided by each firm. Without regulations in this market, one firm's misbehavior will tend to negatively affect other firms through the industry's reputation. Self-regulation can improve the efficiency by regulating the provision of high-quality service and reducing the negative externalities among different firms. Meanwhile, monopoly distortions in the security market are low since consumers can always deposit their money into a traditional banking account. Also, externalities from the securities market to society are small and even close to zero. Therefore, the economic benefit of self-regulation is larger than its cost.

It is also interesting to apply the general insight to self-regulation in the banking industry. Before the establishment of the Federal Reserve System, the banking industry was de facto self-regulated by the New York Clearing House. Afterwards, the self-regulation was replaced by government regulation. My model can help understand such a change. The asymmetric information about the negative externalities between banks used to be large since it was hard for outsiders to understand their internal operation. Today, the government has a better understanding of the banking business, which significantly reduces the information asymmetries. The monopoly distortion also becomes large since the banking industry provides a comprehensive financial service to the general public. Moreover, the externalities from the banking sector to society are very large, as documented by Bernanke (1983).[13] Given the dynamic changes in the banking industry, it was reasonable to have self-regulation in the early days and government regulation today. Nonetheless, it is still worth considering self-regulation as complementary given its flexibility to a changing environment. In the next subsection, I argue that due to the increasing complexity of externalities in the banking sector, the idea of self-regulation is worth considering.

3.4.2 Theoretical Applications

The general insights in our theoretical framework could be applied to many ongoing policy discussions such as macroprudential and banking regulation. In this section, I provide one simple example in the literature that can be mapped into a general theoretical framework.

In the macro/finance literature, two types of distortions are widely analyzed to justify financial regulation—bailout externality and pecuniary externality (see Farhi and Tirole (2012), Keister (2015), Jeanne and Korinek (2010a), Ma (2017), etc.). Bailout funds are essentially externalities from the banking sector (producers in our model) to the general public (consumers) and fire-sale externalities are negative effects between banks. These two types of externalities correspond to consumption externalities $U(X;\Phi)$ and production externality $C(X;\Theta)$ in my general framework. Therefore, policy discussions based on these types of models should have room for self-

[13] The externalities are even larger given the existence of deposit insurance and bailout funds.

regulation. Surprisingly, current policy discussion does not have it. In this section, I provide a simple model with the flavor of both fire-sale externalities and bailout in the spirit of Jeanne and Korinek (2010a) and Jeanne and Korinek (2010b) to analyze the potential role for self-regulation. In the end, I argue that self-regulation should be considered as an alternative to current policy discussions.

The model consists of three time periods $t = 0, 1, 2$ and is inhabited by two types of atomistic agents of mass 1, bankers and investors. Bankers are assumed to be natural borrowers and need to borrow at period 0 and 1 in order to smooth consumption. Investors are assumed to be natural lenders and have affluent endowments available in three periods. The critical feature of this model is a collateral borrowing constraint, as in Jeanne and Korinek (2010a).

Specifically, Bankers have equity e in period 0 and issue debt d_1 to satisfy their consumption c_0. In period 1, after repaying debt d_1,[14] bankers receive an income shock $\tilde{e}$ and 1 unit of asset, which yields a fixed payment y at period 2. Meanwhile, bankers decide the share of asset κ to hold in period 2 and issue another debt d_2 to satisfy consumption c_1. In period 2, bankers receive the payoff from the asset, repay the debt d_2, and consume the remaining amount. However, the bankers' ability to roll over the debt is affected by an imperfect collateral constraint where its value depends on the collateral value. Intuitively, this financial constraint can be rationalized as a limited enforcement or commitment problem in the financial market and thus creates

[14]Here, the interest rate R can be normalized to 1 due to the specific setting of an investor's utility function.

pecuniary externalities. The financial constraint can be expressed as follows.

$$d_2 \leq \phi p$$

where $\phi < 1$ captures the financial friction.

The utility function of the bankers is assumed to be $U^B = c_0 + u(c_1) + c_2$, where in the last period the utility function is assumed to be risk neutral for convenience. Investors are assumed to have an abundant endowment, and their utility functions are $U^I = c_0^I + c_1^I + c_2^I$.

The problem can be solved using backward induction. In period 1, depending on the realization of net worth $m = \tilde{e} - d_1$ there are two states: the unconstrained state where no fire sale happens and the constrained state where the individual banker fire sells his asset. The fire sale creates inefficiencies because the individual does not realize that the asset price is a downward-sloping function and depends on the aggregate net worth of the banking sector, M. In order to map the problem into my general setup, I leave the derivation of value function in Appendix C.2 and write the banker's optimality problem in the fashion of value function in period 0, i.e.

$$\begin{aligned} \max_{d_0} \quad & c_0 + E[V(m; M)] \\ \text{s.t.} \quad & c_0 = d_0 \\ & m = \tilde{e} - d \\ \equiv \max_{d_0} \quad & \underbrace{d_0}_{px_i} + \underbrace{E[V(\tilde{e} - d_0, \tilde{E} - D_0)]}_{-c(x;\theta) - C(X;\Theta)} \end{aligned}$$

To see how this can be mapped into the general framework in Section 3.2, notice that the price of d_0 is 1 and the $E[V(m; M)]$ is the utility function $-c(x; \theta) - C(X; \Theta)$ for producers, where $\{\theta, \Theta\} = \{\tilde{e}, \phi\}$. The appearance of negative externalities in the banking sector provides room for self-regulation and could yield some economic benefit especially when $\{\theta, \Theta\}$ is unobservable to government.

As to the economic cost of self-regulation, one needs to look at the consumers' utility. In the simple case where it is linear and without bailout, there is no cost of self-regulation. But one can imagine that consumers have the utility form of $U^I = u(c_0^I) + c_1^I + c_2^I$ with $u' > 0, u'' < 0$. Then the monopoly distortions need to be taken into account. As for the externalities from the banking sector to society, one needs to think of the existence of bailouts. Imagine that in period 1, whenever there is a binding constraint, the government will bail out the banks. Suppose that the government can only mitigate part of the constraint due to the cost of taxation. Then there is a tax function T in period 1 deducted from consumer's utility and this

T depends on the aggregate level of M. This T function corresponds to the $U(X;\Phi)$ function in my general framework and should be taken into account for the discussion of self-regulation in the banking sector.

Notice that correcting fire-sale externalities requires superior information about $\{\theta, \Theta\}$. Without such information, the policy recommendation, such as the Pigovian tax in Jeanne and Korinek (2010a) is ineffective. Self-regulation, however, could reduce such information asymmetries. An optimal regulatory mechanism in the banking sector should include both government regulation and self-regulation where both focus on different sources of externalities in the economy.

3.5 Conclusion

In this paper, I provide a simple framework for the analysis of self-regulation versus government regulation. I argue that three elements are crucial for the trade-off: externalities, monopoly distortions, and the degree of asymmetric information. Whenever the degree of asymmetric information is larger than the size of monopoly distortions and externalities to society, it is worthwhile to have self-regulation. Moreover, an optimal mechanism consists of both self-regulation and government regulation where self-regulation focuses on externalities in the industry, and government regulation focuses on monopoly distortion and externalities to society.

Based on these insights, I provide some examples to understand real-world observations. Moreover, my work can shed light on current ongoing policy discussions. As long as an economy has the three elements identified in this paper, there is room for analysis of self-regulation versus government regulation. One general takeaway is that optimal regulatory mechanisms should take self-regulation into account.

Future work needs to be done on this paper. For example, the SRO in my model has the same incentive as the government to internalize the negative externalities and does not have a conflict of interest for misusing the superior information from a social perspective. It can enrich the model predictions if the conflict of interest is introduced in the model. Moreover, there is no asymmetric information between producers and consumers in my model. It is interesting to analyze these cases because it might increase the case for self-regulation. After all, SROs can help allieviate the asymmetric information and thus faciliate the transactions between producers and consumers. Last, my model can also be generalized into a dynamic setting in order to analyze the dynamic trade-off between self-regulation and government regulation.

Appendix A

Appendix to Chapter 1

A.1 Data Source

The sample includes the following 55 countries:

Algeria	Argentina	Australia	Austria	Belgium
Brazil	Canada	Chile	China	Colombia
Cote d'Ivoire	Croatia	Czech Republic	Denmark	Dominican Republic
Ecuador	Egypt, Arab Rep.	El Salvador	Finland	France
Germany	Greece	Hungary	Iceland	Indonesia
Ireland	Italy	Japan	Korea, Rep.	Lebanon
Malaysia	Mexico	Morocco	Netherlands	New Zealand
Nigeria	Norway	Pakistan	Panama	Peru
Philippines	Poland	Portugal	Russian Federation	South Africa
Spain	Sweden	Thailand	Tunisia	Turkey
Ukraine	United Kingdom	United States	Uruguay	Venezuela, RB

The sources are as follows:

GDP Per Capita Growth: GDP per capita from World Development Indicators (WDI);

TFP: Pen World Table;

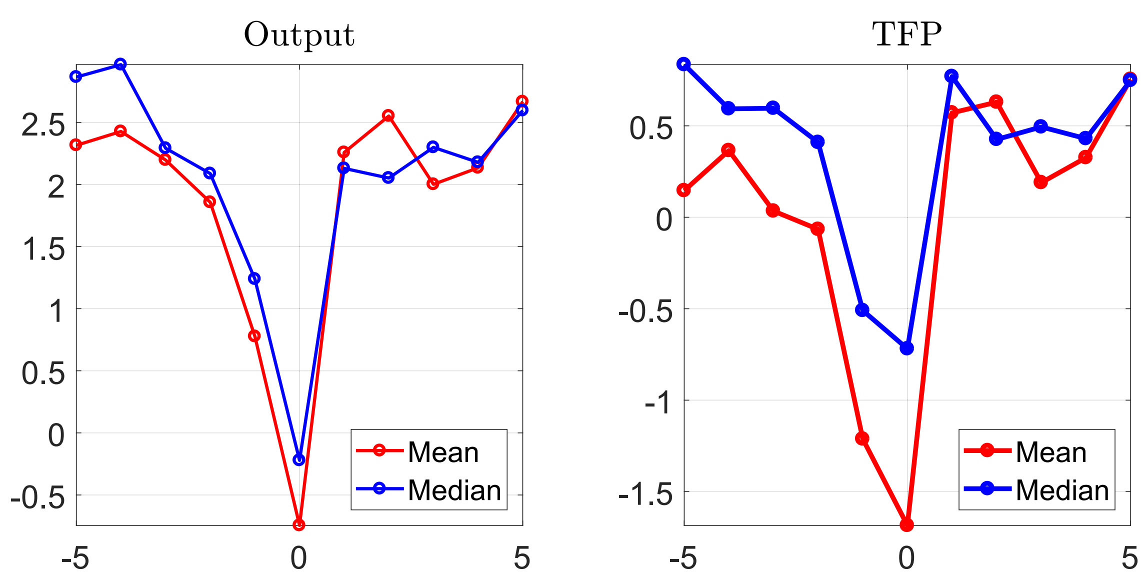
Consumption Share of GDP: calculated using final consumption expenditure and GDP data in WDI;

Net Foreign Asset to GDP Ratio: an updated dataset in Lane and Milesi-Ferretti (2007) (see `http://www.philiplane.org/EWN.html`).

A.2 Empirical Results for KM episodes

I use sudden stop episodes as in Korinek and Mendoza (2014) to show the persistent output-level effects of crises. One can see that this effect is robust to identification of crises. Furthermore, TFP displays a similar pattern to output, as in Figure 1.1.

Figure A.1: Growth Rates in KM episodes (%)



Note: The series are constructed using an 11-year window centering on the sudden stop episodes.

A.3 Normalized Economy

I normalize the economy by the endogenous variable z_t and denote normalized variables by a hat. The normalized competitive equilibrium conditions are given by

$$
\begin{aligned}
&\left(\hat{c}_t^h\right)^{-\gamma}\Psi_{1,t} = \beta g_{t+1}^{-\gamma} E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}(\theta_{t+1} - h - \Psi_{2,t+1})\right] \\
&\left(\hat{c}_t^h\right)^{-\gamma}\hat{q}_t = \beta g_{t+1}^{1-\gamma} E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}(\alpha\theta_{t+1} + \hat{q}_{t+1})\right] \\
&\left(\hat{c}_t^h\right)^{-\gamma} = \hat{\mu}_t^{CE} + \beta g_{t+1}^{-\gamma}(1+r)E_t\left[\left(\hat{c}_{t+1}^h\right)^{-\gamma}\right] \\
&\hat{c}_t^h + \hat{\Psi}(g_{t+1}) + \hat{b}_{t+1}g_{t+1} = \theta_t - h + (1+r)\hat{b}_t \\
&\hat{\mu}_t^{CE}\left(\hat{b}_{t+1}g_{t+1} + \phi\hat{q}_t\right) = 0, \text{with } \hat{\mu}_t^{CE} \geq 0.
\end{aligned}
$$

For the macroprudential social planner, the normalized equilibrium conditions are

$$
\begin{aligned}
&\hat{\lambda}_t^{MP} = \left(\hat{c}_t^h\right)^{-\gamma} + \frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t}{\hat{c}_t^h} + \gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t} \\
&\hat{\lambda}_t^{MP}\Psi_{1,t} - \frac{\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{1,t}}{\left(\hat{c}_t^h\right)^{-\gamma}} - \hat{\nu}_t^{MP}\left[g_{t+1}^{-1-\gamma}\hat{I}_{1,t} - (\hat{c}_t^h)^{-\gamma}\hat{\Psi}_{11,t}\right] \\
&= \beta g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MP}(\theta_{t+1} - h - \Psi_{2,t+1}) - \hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma}\hat{\Psi}_{12,t+1}\right] \\
&\hat{\lambda}_t^{MP} = \hat{\mu}_t^{MP} + \frac{\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}} + \hat{\nu}_t^{MP}g_{t+1}^{-1-\gamma}\hat{I}_{2,t} + \beta(1+r)g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MP}\right]
\end{aligned}
$$

where

$$
\begin{aligned}
&I(z_{t+1}, b_{t+1}) = z_{t+1}^{-\gamma}\hat{I}\left(\hat{b}_{t+1}\right), \\
&I_{1,t} = (-\gamma)z_{t+1}^{-\gamma-1}\hat{I}\left(\hat{b}_{t+1}\right) + z_{t+1}^{-\gamma}\hat{I}'\left(\hat{b}_{t+1}\right)\frac{-b_{t+1}}{z_{t+1}^2} = -z_{t+1}^{-\gamma-1}\left[\gamma\hat{I} + \hat{I}'\hat{b}_{t+1}\right], \\
&I_{2,t} = z_{t+1}^{-\gamma-1}\hat{I}'.
\end{aligned}
$$

and

$$
\begin{aligned}
&G(z_{t+1}, b_{t+1}) = z_{t+1}^{1-\gamma}\hat{G}\left(\hat{b}_{t+1}\right), \\
&G_{1,t} = (1-\gamma)z_{t+1}^{-\gamma}\hat{G}\left(\hat{b}_{t+1}\right) + z_{t+1}^{1-\gamma}\hat{G}'\left(\hat{b}_{t+1}\right)\frac{-b_{t+1}}{z_{t+1}^2} = z_{t+1}^{-\gamma}\left[(1-\gamma)\hat{G} - \hat{G}'\hat{b}_{t+1}\right], \\
&G_{2,t} = z_{t+1}^{-\gamma}\hat{G}'.
\end{aligned}
$$

For the multi-instrument social planner, the normalized equilibrium conditions are

$$
\begin{aligned}
&\hat{\lambda}_t^{MI} = \left(\hat{c}_t^h\right)^{-\gamma} + \frac{\gamma\phi\hat{\mu}_t^{MI}\hat{q}_t}{\hat{c}_t^h} \\
&\hat{\lambda}_t^{MI}\Psi_{1,t} = \frac{\phi\hat{\mu}_t^{MI}g_{t+1}^{-\gamma}\hat{G}_{1,t}}{\left(\hat{c}_t^h\right)^{-\gamma}} + \beta g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MI}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right] \\
&\hat{\lambda}_t^{MI} = \hat{\mu}_t^{MI} + \frac{\phi\hat{\mu}_t^{MI}g_{t+1}^{-\gamma}\hat{G}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}} + \beta(1+r)g_{t+1}^{-\gamma}E_t\left[\hat{\lambda}_{t+1}^{MI}\right]
\end{aligned}
$$

A.4 Proofs

A.4.1 Proof of Proposition 1

Proof. To implement the macroprudential social planner's allocation, I compare the normalized optimality conditions of private agents and of the macroprudential social planner (see Appendix A.3) and find that

$$\begin{aligned}\tau_t^{MP,b} &= \frac{\beta g_{t+1}^{-\gamma}\left(1+r\right)E_t\left[\gamma\phi\hat{\mu}_{t+1}^{MP}\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1}+\gamma\hat{\nu}_{t+1}^{MP}\left(\hat{c}_{t+1}^h\right)^{-\gamma-1}\Psi_{1,t+1}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}} \\ &\quad -\frac{\gamma\phi\hat{\mu}_t^{MP}\hat{q}_t\left(\hat{c}_t^h\right)^{-1}+\gamma\hat{\nu}_t^{MP}\left(\hat{c}_t^h\right)^{-\gamma-1}\Psi_{1,t}-\phi\hat{\mu}_t^{MP}g_{t+1}^{-\gamma}\hat{G}_{2,t}\left(\hat{c}_t^h\right)^{\gamma}-\hat{\nu}_t^{MP}g_{t+1}^{-1-\gamma}\hat{I}_{2,t}}{\left(\hat{c}_t^h\right)^{-\gamma}}\end{aligned}$$

A.4.2 Proof of Proposition 2

Proof. To implement the multi-instrument social planner's allocation, I compare the normalized optimality conditions of private agents and of the multi-instrument social planner (see Appendix A.3) and find that

$$
\begin{aligned}
\tau_t^{MI,z} &= \frac{\beta g_{t+1}^{-\gamma} E_t\left[\hat{c}_{t+1}^{-\gamma}\tau_{t+1}^{MI,z}\Psi_{2,t+1} + \gamma\phi\hat{\mu}_{t+1}^{MI}\hat{q}_{t+1}\left(\hat{c}_{t+1}^{h}\right)^{-1}\left(\theta_{t+1} - h - \Psi_{2,t+1}\right)\right]}{\Psi_{1,t}\left(\hat{c}_t^h\right)^{-\gamma}} \\
&\quad - \frac{\gamma\phi\hat{q}_t\left(\hat{c}_t^h\right)^{-1}\hat{\mu}_t^{MI}\Psi_{1,t} - \phi\hat{\mu}_t^{MI}\left(\hat{c}_t^h\right)^{\gamma} g_{t+1}^{-\gamma}\hat{G}_{1,t}}{\Psi_{1,t}\left(\hat{c}_t^h\right)^{-\gamma}}, \\
\tau_t^{MI,b} &= -\frac{\gamma\phi\hat{q}_t\left(\hat{c}_t^h\right)^{-1}\hat{\mu}_t^{MI} - \phi\hat{\mu}_t^{MI}\left(\hat{c}_t^h\right)^{\gamma} g_{t+1}^{-\gamma}\hat{G}_{2,t} - \beta g_{t+1}^{-\gamma}\left(1+r\right)E_t\left[\gamma\phi\hat{q}_{t+1}\left(\hat{c}_{t+1}^h\right)^{-1}\hat{\mu}_{t+1}^{MI}\right]}{\left(\hat{c}_t^h\right)^{-\gamma}}
\end{aligned}
$$

A.5 Sensitivity Analysis

I conduct sensitivity analysis for different parameters in the model. As with the baseline calibration, I first give values for seven parameters, i.e., $\{\beta, \psi, r, \gamma, \alpha, \rho, \sigma\}$: I only change the value of one parameter while keeping the other parameter values the same, as in the baseline calibration. Given these values, I choose $\{\kappa, h, \phi\}$ to match average growth, the consumption to GDP ratio, and the NFA-GDP ratio. I follow this strategy because I want the model to match average growth, which is affected by consumption's share of GDP and by the NFA-GDP ratio. The sensitivity analysis results are presented in Table A.1, and I discuss the robustness of my results with respect to the parameters. One can see that the results do not change with α, since in the calibration, I assume that the collateral constraint binds in steady state, and that ϕ changes with α.

Table A.1: Sensitivity Analysis

Panel A

	Welfare Gains (%)						Tax on Capital Flows (%)			
	MP (overall)	MP (growth)	MP (consumption)	MI (overall)	MI (growth)	MI (consumption)	MP	MI (average)	MI (ex-ante)	MI (ex-post)
baseline	0.06	−0.34	0.40	0.24	−0.13	0.38	1.28	1.12	1.10	1.19
$\beta = 0.93$	0.01	−0.04	0.05	0.09	−1.04	1.14	1.51	0.76	5.03	0.11
$\beta = 0.95$	0.03	−0.17	0.20	0.18	−0.82	1.01	1.67	1.17	2.95	0.23
$\psi = 0.94$	0.12	−0.48	0.59	0.36	−0.05	0.41	1.65	1.30	1.20	1.74
$\psi = 0.96$	0.03	−0.16	0.18	0.15	−0.17	0.33	1.04	0.90	1.14	0.17
$\phi = 0.07$	0.01	−0.12	0.13	0.10	−0.19	0.29	0.81	0.80	1.19	−0.40
$\phi = 0.08$	0.02	−0.17	0.20	0.16	−0.17	0.33	0.94	0.93	1.15	0.23
$r = 3\%$	0.12	−0.56	0.69	0.49	−1.30	1.82	2.59	2.12	2.83	1.54
$r = 4\%$	0.10	−0.41	0.51	0.38	−0.74	1.14	1.92	1.23	1.63	0.35
$\gamma = 3$	0.21	−1.13	1.40	1.42	−4.06	5.77	2.38	2.44	3.14	1.96
$\gamma = 4$	0.43	−1.77	2.19	3.78	−14.20	21.19	3.03	3.90	7.22	3.29
$\alpha = 0.3$	0.06	−0.34	0.40	0.24	−0.14	0.39	1.28	1.12	1.10	1.19
$\alpha = 0.4$	0.06	−0.34	0.40	0.24	−0.14	0.39	1.28	1.12	1.10	1.19
$\rho = 0.80$	0.05	−0.34	0.40	0.23	−0.19	0.43	1.37	1.09	1.05	1.20
$\rho = 0.90$	0.03	−0.31	0.33	0.25	−0.05	0.30	1.35	0.09	0.39	−2.38
$\sigma = 0.02$	0.02	−0.08	0.10	0.10	−0.51	0.62	0.93	0.96	1.81	0.56
$\sigma = 0.03$	0.03	−0.19	0.22	0.17	−0.35	0.52	1.22	1.18	1.34	1.00

Panel B

	Subsidy on Growth (%)			Prob. of Crisis (%)			Average GDP Growth (%)			Reverse in Growth
	MI (average)	MI (ex-ante)	MI (ex-post)	CE	MP	MI	CE	MP	MI	MI
baseline	1.00	1.87	−1.78	6.23	1.89	14.23	2.315	2.307	2.289	17.51
$\beta = 0.93$	−1.40	4.27	−2.27	13.24	12.39	13.84	2.315	2.312	2.197	1.87
$\beta = 0.95$	−0.18	3.34	−2.04	10.83	9.52	13.66	2.318	2.312	2.240	3.39
$\psi = 0.94$	1.49	2.06	−1.14	2.86	1.89	15.33	2.323	2.311	2.292	23.22
$\psi = 0.96$	0.54	1.65	−2.94	7.32	2.06	12.36	2.308	2.305	2.287	13.16
$\phi = 0.07$	0.35	1.55	−3.27	7.27	6.66	11.56	2.308	2.306	2.289	11.00
$\phi = 0.08$	0.60	1.71	−2.83	7.43	2.34	12.96	2.311	2.307	2.288	15.24
$r = 3\%$	1.26	4.20	−1.11	7.84	6.26	14.29	2.336	2.312	2.238	5.29
$r = 4\%$	0.80	2.52	−2.89	7.35	2.49	16.18	2.323	2.310	2.260	7.33
$\gamma = 3$	0.64	3.94	−1.59	10.49	7.00	15.33	2.363	2.352	2.246	5.28
$\gamma = 4$	−0.65	6.40	−1.94	12.12	10.65	16.24	2.392	2.382	2.149	3.84
$\alpha = 0.3$	1.00	1.87	−1.78	6.23	1.89	14.23	2.315	2.307	2.288	17.19
$\alpha = 0.4$	1.00	1.87	−1.78	6.23	1.89	14.23	2.315	2.307	2.288	17.18
$\rho = 0.80$	0.84	1.92	−2.10	5.93	2.22	15.12	2.295	2.287	2.265	14.87
$\rho = 0.90$	0.19	0.72	−4.26	4.72	2.20	12.66	2.287	2.278	2.259	21.78
$\sigma = 0.02$	0.40	2.63	−0.64	10.91	8.29	13.95	2.297	2.296	2.257	5.46
$\sigma = 0.03$	0.87	2.25	−0.75	7.38	6.75	15.72	2.303	2.300	2.270	9.14

Note: Welfare gains and taxes on debt are calculated by simulating the economy for 10,000 periods. Crises are defined as periods when the collateral constraint binds and the current account reversal exceeds 1 standard deviation of its long-run average.

Impacts on Growth: The negative relationship between average growth and financial stability for the macroprudential social planner is very robust to all the parameter values. The multi-instrument social planner could generate a short-run growth spurt. In the baseline results, the growth spurt lasts for 18 years. I find that this number varies with different parameter values. Generally speaking, it is related to the welfare loss in the trend component of the consumption channel. The duration is longer if the multi-instrument social planner generates fewer welfare losses in this channel.

Welfare Gains: The results on welfare gains are robust to various parameters. In particular, I find that the macroprudential social planner can generate welfare gains equivalent to a 0.06 percent permanent increase in annual consumption, while the multi-instrument social planner can generate larger gains, equivalent to a 0.24 percent permanent increase in annual consumption. In particular, the size of gains increases with parameters that affect the size of externalities, such as ϕ. The gains also increase with parameters that make growth more sensitive to shocks, such as $\{\psi, \gamma\}$. Given that the social planners smooth the economy, welfare gains also increase with parameters that govern risk, such as $\{\rho, \sigma\}$.[1] The welfare gains are supposed to decrease with the discount rate β and the interest rate r, since they decide private agents' impatience condition, given by $\beta(1+r)g^{-\gamma}$. Intuitively, when agents are more impatient, i.e., there is a lower β or r, the economy borrows more and ends up with

[1] Here, lower ρ implies a higher risk for the economy, since it is more likely to enter a bad state tomorrow conditional on a good state today.

more crises. Policy interventions should have more benefits, since they mitigate the frequency and severity of crises. Indeed, I find larger gains with a lower interest rate. However, I also find that welfare gains increase with β. This is because β decides the Euler equation of productivity. High β means that private agents care more about the reduction of growth during crisis. Hence, policy interventions can generate larger benefits by reducing this reduction.

Size of Interventions: In the baseline results, I find that the macroprudential social planner imposes a 1.28 percent capital flows tax, while the multi-instrument social planner imposes a 1.12 percent capital flows tax and a 1.00 percent subsidy on growth-enhancing expenditures. Furthermore, there is a difference when looking at the multi-instrument social planner's taxes from the ex-ante and the ex-post perspective. Generally speaking, the magnitude of the macroprudential capital flows tax varies with different parameters and depends on the size of externalities and the ergodic distribution of debt. For the multi-instrument social planner, it is a robust feature that she taxes borrowing and subsidizes growth-enhancing expenditures ex-ante. Ex-post, she always taxes growth-enhancing expenditures to relax the borrowing constraint and might also want to subsidize borrowing, depending on the tightness of the constraint. Hence, I find that it is not true that the multi-instrument social planner always imposes a lower ex-ante capital flows tax than the macroprudential social planner. In some cases, she actually chooses a much higher tax on borrowing, reflecting a stronger precautionary motive.

A.6 Numerical Methods for Solving Policy Functions

I first create a grid space $\mathcal{G}_b = \{\hat{b}^0, \hat{b}^1, \cdots\}$ for the bond holding $\hat{b}_t$ and a grid space $\Theta = \{\theta_1, \cdots, \theta_5\}$ for the exogenous technology shock θ_t. The discretization method for the log AR (1) process of θ_t follows the Rouwenhorst method, as in Kopecky and Suen (2010). I apply the endogenous gridpoint method as in Carroll (2006) to iterate first-order conditions in CE, MP, and MI, and the iteration stops until policy functions converge. Policy functions in competitive equilibrium include consumption $\mathcal{C}(\hat{b}_t, \theta_t)$, endogenous growth $\mathcal{G}(\hat{b}_t, \theta_t)$, asset price $\mathcal{Q}(\hat{b}_t, \theta_t)$, and bond holding $\mathcal{B}(\hat{b}_t, \theta_t)$. Denote the iteration step by j and start from arbitrary policy functions $\mathcal{C}^0(\hat{b}_t, \theta_t)$, $\mathcal{G}^0(\hat{b}_t, \theta_t)$, $\mathcal{Q}^0(\hat{b}_t, \theta_t)$, and $\mathcal{B}^0(\hat{b}_t, \theta_t)$, where 0 means the iteration step $j = 0$. Given policy functions in iteration step j, I solve policy functions for iteration $j + 1$ as follows:

1. For any $\theta_t \in \Theta$ and $\hat{b}_{t+1} \in \mathcal{G}_b$, I can solve $\{\hat{c}_t^h, g_{t+1}, \hat{q}_t\}$ using equilibrium conditions. Using the budget constraint, these allocations imply a unique $\hat{b}_t$. Then I have a combination of $\{\hat{b}_t\}$ and corresponding allocations $\{\hat{c}_t^h, g_{t+1}, \hat{q}_t, \hat{b}_{t+1}\}$. I can update policy functions using these combinations. In this process, I need to deal with the collateral constraint. Specifically, I assume that the constraint is slack and then check whether this condition is satisfied.

2. I first assume that the constraint is slack and allocations $g_{t+1}, \hat{c}_t^h, \hat{q}_t$ can be solved

using the following conditions:

$$\begin{aligned}
\Psi_t(g_{t+1}) &= \frac{E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}\left(\theta_{t+1}-h-\Psi_2\left(\mathcal{G}^j(\hat{b}_{t+1},\theta_{t+1})\right)\right)\right]}{(1+r)E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}\right]} \\
\hat{c}_t^h &= g_{t+1}\left[\beta(1+r)E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}\right]\right]^{-\frac{1}{\gamma}} \\
\hat{q}_t &= \left(\hat{c}_t^h\right)^{\gamma}\beta g_{t+1}^{1-\gamma}E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}(\alpha\theta_{t+1}+\mathcal{Q}(\hat{b}_{t+1},\theta_{t+1}))\right]
\end{aligned}$$

3. If the collateral constraint $-\hat{b}_{t+1}g_{t+1} \leq \phi\hat{q}_t$ is satisfied, I proceed to solve $\hat{b}_t$ using the budget constraint:

$$\hat{b}_t = \frac{\hat{c}_t^h + h + \hat{\Psi}(g_{t+1}) + \hat{b}_{t+1}g_{t+1} - \theta_t}{1+r}$$

4. If the constraint is violated, I can solve allocations $\{\hat{q}_t, \hat{c}_t^h, g_{t+1}\}$ using the following equations:

$$\begin{aligned}
\left(\hat{c}_t^h\right)^{-\gamma}\Psi_t(g_{t+1}) &= \beta g_{t+1}^{-\gamma}E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}\left(\theta_{t+1}-h-\Psi_2\left(\mathcal{G}^j(\hat{b}_{t+1},\theta_{t+1})\right)\right)\right] \\
-\hat{b}_{t+1}g_{t+1} &= \phi\hat{q}_t \\
\hat{q}_t &= \left(\hat{c}_t^h\right)^{\gamma}\beta g_{t+1}^{1-\gamma}E_t\left[\left(\mathcal{C}^j(\hat{b}_{t+1},\theta_{1+1})\right)^{-\gamma}(\alpha\theta_{t+1}+\mathcal{Q}(\hat{b}_{t+1},\theta_{t+1}))\right]
\end{aligned}$$

5. I can update policy functions using the combinations of $\hat{b}_t$ and $\{g_{t+1}, \hat{c}_t^h, \hat{q}_t, \hat{b}_{t+1}\}$.

6. I keep iterating until policy functions in two consecutive iterations are close

enough.

To solve policy functions for the two social planners, I need to solve additional policy functions of Lagrangian multipliers, such as $\mu(\hat{b}_t, \theta_t)$ and $\nu(\hat{b}_t, \theta_t)$, using equilibrium conditions described in Appendix A.3. Otherwise, the procedure is the same as above.

Appendix B

Appendix to Chapter 2

B.1 Normalized Economy

In this appendix we show the derivation of the normalized economy starting from the original setup. As described in the main text, the original economy has the following structure:

Preference.

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\frac{C_t^{1-\gamma}}{1-\gamma}\right]$$

Total Income.

$$Y_t = F_t + p_t Q_t$$

Budget Constraint under No Default.

$$C_t + q_t B_{t+1} + \alpha Q_{t+1} \xi(\bar{p}_t) = Y_t + B_t$$

where agents hedge Q_{t+1} production of oil at period t.

Budget Constraint under Default.

$$C_t = Y_t - H(Y_t)$$

where $H(Y_t) = h(y_t)F_t$.

Given that F_t grows at a constant rate G in every period, C_t and B_{t+1} grow at the same rate as F_t and F_{t+1} respectively. In order to solve a stationary problem, we can normalize the consumers' preferences, total income, and the budget constraints as follows.

Normalized Preference.

$$E_0\left[\sum_{t=0}^{\infty}\beta^t \frac{C_t^{1-\gamma}}{1-\gamma}\right] = E_0\left[\sum_{t=0}^{\infty}\beta^t \frac{(F_t c_t)^{1-\gamma}}{1-\gamma}\right] = F_0 E_0\left[\sum_{t=0}^{\infty}\beta^t \frac{\left(\frac{F_t}{F_{t-1}}\frac{F_t-1}{F_{t-2}}\cdots\frac{F_1}{F_0}c_t\right)^{1-\gamma}}{1-\gamma}\right] = F_0 E_0\left[\sum_{t=0}^{\infty}\beta^t \frac{(G^t c_t)^{1-\gamma}}{1-\gamma}\right]$$

Normalized Total Income.

$$y_t = \frac{Y_t}{F_t} = \frac{F_t + p_t Q_t}{F_t} = 1 + p_t \frac{Q_t}{F_t} = 1 + p_t \mathcal{Q}$$

Normalized Budget Constraint under No Default.

$$y_t+b_t = \frac{Y_t + B_t}{F_t} = \frac{C_t + q_t B_{t+1} + \alpha Q_{t+1}\xi(\bar{p}_t)}{F_t} = c_t+q_t\frac{F_{t+1}}{F_t}\frac{B_{t+1}}{F_{t+1}}+\alpha\frac{Q_{t+1}}{F_{t+1}}\frac{F_{t+1}}{F_t}\xi(\bar{p}_t) = c_t+q_tGb_{t+1}+\alpha\mathcal{Q}G\xi(\bar{p}_t)$$

Normalized Budget Constraint under Default.

$$c_t = \frac{C_t}{F_t} = \frac{Y_t - H(Y_t)}{F_t} = y_t - h(y_t)$$

Given the normalized preferences, total income, and the budget constraints, we can solve the normalized economy problem knowing that the original problem can always be recovered by multiplying all variables by F_t.

B.2 Proofs

B.2.1 Proof of Proposition 3

Proof. If the economy defaults in H state, it must default in L state since $y^H > y^L$. Conditional on no default, optimal borrowing d^* satisfies the following condition:

$$\frac{1}{y + d^*} = \beta\left(\frac{p}{y^H - d^*} + \frac{1-p}{y^L - d^*}\right)$$

The economy finds it optimal not to default iff $y^L - d^* > y^{def}$.

Similarly, when the economy defaults only in L state, optimal borrowing d^{**} satisfies

$$\frac{p}{y + pd^{**}} = \beta \frac{p}{y^H - d^{**}}$$

which is consistent iff $y^H - d^{**} > y^{def}$. Define $\hat{y}^{def} = y^L - d^*$ and $\hat{\hat{y}}^{def} = y^H - d^{**}$ and we establish the first part of the proposition.

In an economy with hedging, optimal borrowing $d^{*,hedge}$ with no default satisfies the following condition:

$$\frac{1}{y + d^{*,hedge} - \xi} = \beta \left(\frac{p}{y^H - d^{*,hedge}} + \frac{1-p}{\bar{y} - d^{*,hedge}} \right)$$

It is not hard to find $d^{*,hedge} > d^*$ since the marginal benefit of borrowing increases and the marginal cost of borrowing declines. Using the same logic, we find that $d^{**,hedge} > d^{**}$. This implies that $\bar{\bar{y}}^{def,hedge} < \hat{\hat{y}}^{def}$. However, $\bar{y}^{def,hedge} > \hat{y}^{def}$ since $c_1^{L,hedge} > c_1^L$ due to the presence of hedging. □

B.2.2 Proof of Proposition 4

Proof. If the economy does not default in equilibrium, the interest rate on debt is 1 and the optimal allocation is given by

$$\frac{1}{y + d^*} = \beta \left(\frac{p}{y^H - d^*} + \frac{1-p}{y^L - d^*} \right).$$

With the introduction of hedging, the optimality condition becomes

$$\frac{1}{y + d^{*,hedge} - \xi} = \beta \left(\frac{p}{y^H - d^{*,hedge}} + \frac{1-p}{\bar{y} - d^{*,hedge}} \right).$$

It is easy to see that $d^{*,hedge} > d^*$ since the income in first period is reduced by ξ and income in L state has increased by $\bar{y} - y^L$.

We also needs to establish the results that social welfare has been increased. Intuitively, hedging does not change the PDV of income stream but reduces the variance of income. This is beneficial since it increases the welfare in the second period. Denote the social welfare without and with hedging by $U_0(d^*)$ and $U_0^{hedge}(d^{*,hedge})$ respectively. We want to show $U_0^{hedge}(d^{*,hedge}) > U_0(d^*)$ by proving $U_0^{hedge}(d^* + \xi(\bar{y})) > U_0(d^*)$. To see it, we have

$$\begin{aligned}
U_0^{hedge}(d^* + \xi(\bar{y})) - U_0(d^*) &= \beta \left[p \log \left(y^H - \xi(\bar{y}) - d^* \right) + (1-p) \log \left(\bar{y} - \xi(\bar{y}) - d^* \right) \right] \\
&\quad - \beta \left[p \log \left(y^H - d^* \right) + (1-p) \log \left(y^L - d^* \right) \right] \\
&= \beta p \log \left(y^H - (1-p)(\bar{y} - y^L) - d^* \right) \\
&\quad + \beta (1-p) \log \left(y^L + p(\bar{y} - y^L) - d^* \right) \\
&\quad - \beta \left[p \log \left(y^H - d^* \right) + (1-p) \log \left(y^L - d^* \right) \right] > 0
\end{aligned}$$

where the last inequality holds since the function

$$f(x) = \beta \left[p \log \left(y^H - (1-p)x - d^*\right) + (1-p) \log \left(y^L + px - d^*\right)\right]$$

increases in $x \in [0, y^H - y^L]$. □

B.2.3 Proof of Proposition 5

Proof. When the economy defaults only in the low-income state of nature, hedging is beneficial if it reduces default incentives. If the economy does not default in equilibrium, social welfare increases with hedging (See Proposition 4). However, debt might increase or decrease. One can see that from the first order conditions with debt d^{**} and $d^{*,hedge}$ satisfying

$$\begin{aligned}
\frac{p}{y + pd^{**}} &= \beta \frac{p}{y^H - d^{**}} \\
\frac{1}{y + d^{*,hedge}} &= \beta \left(\frac{p}{y^H - d^{*,hedge}} + \frac{1-p}{\bar{y} - d^{*,hedge}} \right)
\end{aligned}$$

It is hard to sign d^{**} and $d^{*,hedge}$ since both the marginal benefit and the marginal cost of borrowing increase with hedging.

If hedging does not change default incentives, social welfare is lower since the economy borrows more (See the proof of Proposition 4 in Appendix B.2.2) and consumption streams are unambiguously lower. Clearly, social welfare is further reduced if hedging increases default incentives. There is no borrowing in this case. □

B.2.4 Proof of Proposition 6

Proof. The two-period model with forwards changes into the following form

$$\begin{aligned} U_0^{forwards} &= \max_d \log c_0 + \beta \log c_1 \\ \text{s.t.} \quad & c_0 = y + d, \\ & c_1 = \max\{\bar{y} - d, y^{def}\} \end{aligned}$$

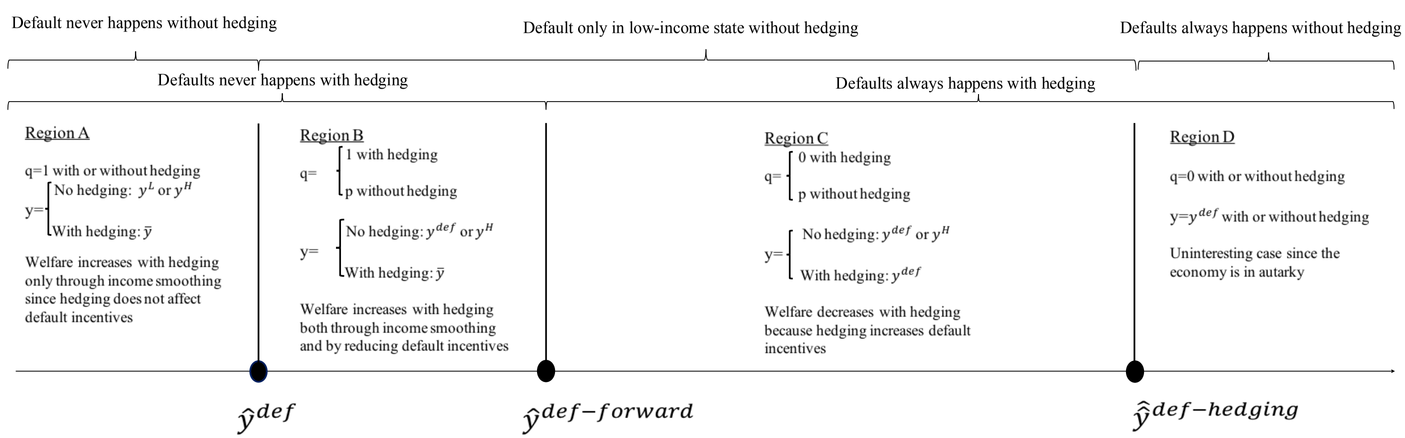
where $\bar{y} = py^H + (1-p)y^L$.

The optimality condition when the economy does not default implies that

$$\frac{1}{y + d^{*,forwards}} = \beta \frac{1}{\bar{y} - d^{*,forwards}}$$

It is easy to show that $d^* < d^{*,forwards}$ since the marginal cost of borrowing

Figure B.1: Two-period Model with Forwards



Source: Authors' construction.

decreases with forwards.[1] Therefore, we have

$$\beta\frac{1}{\bar{y}-d^{*,forwards}}=\frac{1}{y+d^{*,forwards}}<\frac{1}{y+d^{*}}=\beta\left(\frac{p}{y^H-d^*}+\frac{1-p}{y^L-d^*}\right)<\beta\frac{1}{y^L-d^*},$$

which implies that $\bar{y}-d^{*,forwards}>y^L-d^*$. It follows that $\hat{y}^{def,forwards}>\hat{y}^{def}$. However, it is hard to sign $\hat{y}^{def,forwards}$ and $\hat{\hat{y}}^{def}$. As to welfare, if both economies default in both states, economy with forwards has larger utility due to concavity of log function. If economy defaults and forwards avoid default, welfare is larger in the forwards economy. If economy defaults in low state and forwards economy defaults in both states, welfare is lower in the forwards economy. $\square$

B.3 Algorithm

We solve the model using value function iteration. We create grid spaces for both b_t and p_t and denote them by $\mathscr{B}$ and $\mathscr{P}$ respectively. Starting from an initial guess for the bond price function $q_i(b',p)$ for each $b\in\mathscr{B}$ and $p\in\mathscr{P}$ for iteration $i=0$, we implement the following algorithm:

1. Staring from an initial guess of $\{V_i(b,p),V_i^d(p),V_i^c(b,p)\}$ for each $b\in\mathscr{B}$ and $p\in\mathscr{P}$ for iteration $i=0$.

[1] One can see that from the inequality

$$f(x)=\frac{p}{y^H-d}+\frac{1-p}{y^L-d}-\frac{1}{\bar{y}-d}=\frac{p(1-p)\left(y^H-y^L\right)^2}{(y^H-d)(y^L-d)(\bar{y}-d)}>0$$

2. Update $V^d_{i+1}(p)$ using equation (2.8),

3. Update $V^c_{i+1}(b,p)$ according to equation (2.7).

4. Update $V_{i+1}(b,p)$ using $V_{i+1}(w,p) = \max\left\{V^c_{i+1}(b,p), V^d_{i+1}(p)\right\}$.

5. Calculate the implied bond price as follows

$$q_{i+1}(b',p) = \frac{E_{p'|p}\left[V^c_{i+1}(b',p') \geq V^d_{i+1}(p')\right]}{1+r^*}$$

6. Iterate until the endogenous objectives $q_j(b',p), V_j(b,p), V^c_j(b',p')$ and $V^d_j(p)$ are close enough for $j=i$ and $j=i+1$.

B.4 Estimation of Oil Price Process

We estimate an AR(1) process for the oil price in logs, with the unconditional oil price given by $\widehat{p} = \frac{1}{T}\sum_{t=1}^{T} p_t$. We then impose the following functional form to get an estimator for the AR(1) coefficient:

$$\log p_t = \underbrace{(1-\rho)\left[\log(\hat{p}) - \frac{1}{2}\frac{\sigma^2}{1-\rho^2}\right] + \rho \log p_{t-1}}_{\mu_{t-1}} + \varepsilon_t,$$

with conditional density

$$f\left(\log p_t | p_{t-1}, p, \rho, \sigma^2\right) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\log p_t - \mu_{t-1})^2}{2\sigma^2}}$$

The likelihood can be written as:

$$L = \Pi_{t=2}^{T} \tfrac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\log p_t - \mu_{t-1})^2}{2\sigma^2}}$$

$$\log L = -\tfrac{T-1}{2}\log(2\pi\sigma^2) - \tfrac{1}{2\sigma^2}\textstyle\sum_{t=2}^{T}(\log p_t - \mu_{t-1})^2$$

The first order conditions require:

$$\tfrac{\partial \log L}{\partial \rho} = -\tfrac{1}{2\sigma^2}\textstyle\sum_{t=2}^{T} 2(\log p_t - \mu_{t-1})(-\log p_{t-1}) = 0$$

$$\tfrac{\partial \log L}{\partial \sigma^2} = -\tfrac{T-1}{2\sigma^2} + \tfrac{1}{2(\sigma^2)^2}\textstyle\sum_{t=2}^{T}(\log p_t - \mu_{t-1})^2 = 0$$

B.5 Option Pricing

The payoff of the put options is given by $\max\{\bar{p} - p_{t+1}, 0\}$ for strike price $\bar{p}$ and current price p_t at time t. For a risk neutral investor, the put option is priced according to the following formula:

$$\xi(p_t) = \frac{E_t\left[\max\{\bar{p} - p_{t+1}, 0\}\right]}{1 + r^*}$$

Since we assume that $\log p_t$ follows an AR(1) process, i.e.

$$\log p_{t+1} \sim N\left(\underbrace{(1-\rho)\left[\log(p) - \frac{1}{2}\frac{\sigma^2}{1-\rho^2}\right] + \rho \log p_t}_{\mu_t}, \sigma^2\right)$$

Hence, we have

$$\begin{aligned}
\xi(p_t) &= \frac{E_t\left[\max\{\bar{p} - p_{t+1}, 0\}\right]}{1+r^*} \\
&= \frac{\int_{\log p_{t+1} \leq \log \bar{p}} (\bar{p} - p_{t+1})}{1+r^*} \\
&= \frac{1}{1+r^*}\int_{-\infty}^{\log \bar{p}} (\bar{p} - p_{t+1}) \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\log p_{t+1} - \mu_t)^2}{2\sigma^2}} d\log p_{t+1} \\
&= \frac{\bar{p}}{1+r^*}\Phi\left(\frac{\log \bar{p} - \mu_t}{\sigma}\right) - \frac{1}{1+r^*}\int_{-\infty}^{\log \bar{p}} p_{t+1} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\log p_{t+1} - \mu_t)^2}{2\sigma^2}} d\log p_{t+1} \\
&= \frac{\bar{p}}{1+r^*}\Phi\left(\frac{\log \bar{p} - \mu_t}{\sigma}\right) - \frac{1}{1+r^*} e^{\mu_t + \frac{\sigma^2}{2}} \Phi\left(\frac{\log \bar{p} - \mu_t - \sigma^2}{\sigma}\right)
\end{aligned}$$

Appendix C

Appendix to Chapter 3

C.1 Proofs

C.1.1 Proof of Lemma 1

Proof. The objective function for a benevolent government is

$$\max_{X^G} E\left[u(X;\phi) - U(X;\Phi) - c(X;\theta) - C(X;\Theta)\right]$$

The optimality condition is

$$E[u'(X^G;\phi)] = E[U'(X^G;\Phi) + c'(X^G;\theta) + C'(X^G;\Theta)] \tag{C.1}$$

To implement X^G, government could impose restrictions on individual production $x_i \leq X^G$. To see how it works, realize that $X^G < X^{CE}$. Otherwise, $X^G \geq X^{CE}$. The following relation implies a contradiction.

$$\begin{aligned}
0 &= E[u'(X^G;\phi) - U'(X^G;\Phi) - c'(X^G;\theta) - C'(X^G;\Theta)] \\
&\leq E[u'(X^{CE};\phi) - U'(X^G;\Phi) - c'(X^{CE};\theta) - C'(X^G;\Theta)] \\
&\leq -E[U'(X^G;\Phi) + C'(X^G;\Theta)] \\
&< 0
\end{aligned}$$

Therefore, government can impose a restriction $x_i \leq X^G$ to individual producer and it binds always. □

C.1.2 Proof of Lemman 2

Proof. The objective function for an SRO is

$$\begin{aligned}
&\max_{X^S} \quad p(X^S;\phi)X^S - c(X^S;\theta) - C(X^S;\Theta) \\
&\text{s.t.} \quad p(X^S;\phi) = u'(X^S;\phi)
\end{aligned}$$

The optimality condition is

$$u'(X^S;\phi) + u''(X^S;\phi)X^S = c'(X^S;\theta) + C'(X^S;\Theta) \tag{C.2}$$

Equivalently, it can be written as

$$u'(X^S;\phi)\left(1-\frac{1}{E_d(X^S;\phi)}\right)=c'(X^S;\theta)+C'(X^S;\Theta)$$

where $E_d(X^S;\phi)$ is the price elasticity of demand at the point $X = X^S$.

To implement X^S, SRO could impose restrictions on individual production $x_i \leq X^S$. To see how it works, realize that $X^S < X^{CE}$ due to the following relationship.

$$\begin{aligned} & u'(X^{CE};\phi)-c'(X^{CE};\theta)=0 \\ < \;& -u''(X^S;\phi)X^S+C'(X^S;\Theta) \\ = \;& u'(X^S;\phi)-c'(X^S;\theta) \end{aligned}$$

Then an SRO can impose a restriction $x_i \leq X^S$ to individual producer and it binds always. □

C.1.3 Proof of Proposition 7

Proof. If government has perfect information about $\mathcal{F}$, it can choose X^{FB} defined by the optimality condition (3.2). Furthermore, $X^{FB} < X^{CE}$.

To implement X^{FB}, government can regulate either consumers or producers. To regulate the consumers, government can use a Pigovian tax τ on individual consumers and rebate them by a lump-sum transfer T. For the individual consumer j, his objective function is thus

$$\max_{y_j} u(y_j; \phi) - (p + \tau) y_j - U(X; \Psi) + T$$

The optimality condition is

$$p + \tau = u'(y_j; \phi)$$

The optimality condition for producers is unaffected by the policy. Therefore, in equilibrium, the following relationship holds.

$$\tau = u'(X; \phi) - c'(X; \theta)$$

To implement the first best allocation, one can choose $\tau = U'(X^{FB}; \Phi) + C'(X^{FB}; \Theta)$ and $T = \tau X^{FB}$. Furthermore, one can simply put a quantity restriction $y^j \leq X^{FB}$ on the individual consumer and implement the first best allocation. The reason is that $X^{FB} < X^{CE}$ in equilibrium.

By a similar argument, one can easily show that the first best allocation X^{FB} can be implemented by a tax τ_0^* and a lump-sum transfer T_0^* on an individual producer.

For individual producer i, his objective function is thus

$$\max_{x_i}(p+\tau_0^*)x_i - c(x_i;\theta) - C(X;\Theta) + T_0^*$$

The optimality condition is thus

$$p+\tau_0^* = c'(x_i;\theta)$$

The optimality condition for consumers is unaffected by the policy. Therefore, in equilibrium, the following relation holds.

$$\tau_0^* = c'(X;\theta) - u'(X;\phi)$$

By monotonicity of $c'-u'$, choosing $\tau_0^* = -U'(X^{FB};\Phi) - C'(X^{FB};\Theta)$ can implement X^{FB} in the decentralized economy. Also $T_0^* = -\tau_0^* X^{FB}$ is implied by government's budget constraint. Similarly, one can also put a production restriction $x^i \leq X^{FB}$ to implement X^{FB} because $X^{CE} > X^{FB}$ in equilibrium.

Now, we consider a case where the government allows the producers to form a industrial SRO and regulates the SRO instead. The SRO thus faces the following maximization problem.

$$\max_{X}(u'(X;\phi)+\tau_1^*)X - c(X;\theta) - C(X;\Theta) + T_1^*$$

The optimality condition is thus

$$u'(X;\phi) + \tau_1^* + u''(X;\phi)X = c'(X;\theta) + C'(X;\Theta)$$

Hence, one can choose $\tau_1^* = -u''(X^{FB};\phi)X^{FB} - U'(X^{FB};\Phi)$ and $T_1^* = -\tau_1^* X^{FB}$ to implement X^{FB}.

Interestingly, if $\tau_1^* = -u''(X^{FB};\phi)X^{FB} - U'(X^{FB};\Phi) > 0$, it implies that $X^S < X^{FB} < X^{CE}$. In other words, government needs to subsidize an SRO to implement the first best allocation. It turns out that there exists a specific number of monopolistic competitive SROs such that the first best allocation X^{FB} can be implemented. To see this point, first assume that there exists N SROs in the market for self-regulation and each has a market share of $\frac{1}{N}$. For each of them, the maximization problem is as follows.

$$\begin{array}{ll} \max\limits_{X_i} & P\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\phi\right)X_i - c(X_i;\theta) - C\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\Theta\right) \\ \text{s.t.} & P\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\phi\right) = u'\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\phi\right) \end{array}$$

The optimality condition is

$$\frac{1}{N}u''\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\phi\right)X_i + u'\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\phi\right) = c'(X_i;\theta) + \frac{1}{N}C'\left(\frac{X_i}{N} + \sum_{j\neq i}\frac{X_j}{N};\Theta\right)$$

By symmetry, it implies

$$\frac{1}{N}u''(X^N;\phi)X^N + u'(X^N;\phi) = c'(X^N;\theta) + \frac{C'(X^N;\Theta)}{N}$$

Realize that if $N = 1$, there is only one SRO in the market and $X^1 = X^S$; if $N = \infty$, there is a continuum of agents in the market and $X^\infty = X^{CE}$. Moreover, X^N is an increasing function of N. Therefore, if $X^S < X^{FB} < X^{CE}$, by continuity there exists N^* such that $X^{N^{FB}} = X^{FB}$. □

C.1.4 Proof of Proposition 8

Proof. Suppose government announces $\tau(X;\phi)$ to an SRO and rebates it by $T = -\tau(X;\phi)X$. The objective function for the SRO is

$$\begin{aligned} \max_X \quad & [P(X;\phi) + \tau(X;\phi)]X - c(X;\theta) - C(X;\theta) + T \\ \text{s.t.} \quad & P(X;\phi) = u'(X;\phi) \end{aligned}$$

Notice that by choosing $\tau(X;\phi) = -u'(X;\phi) + \frac{u(X;\phi)-E[U(X;\Phi)]}{X}$, the SRO chooses the second best allocation as in (3.3) □

C.1.5 Proof of Proposition 9

Proof. By choosing the price menu as $P(X) = E[u'(X;\phi) - U'(X;\Phi)]$, the government can implement $\bar{\bar{W}}$. To implement, government buys goods from an SRO according to such price menu and sells to the consumer. The difference between selling and buying is transferred to the SRO. $\square$

C.2 Derivation of Value Function

In period 1, define the state variable as $m = \tilde{e} - d_1$ and $M = m$ in equilibrium. The value function can be written as

$$
\begin{aligned}
V(m; M) = \quad & \max_{d_2,\theta} \; u(c_1) + c_2 \\
\text{s.t.} \quad & c_1 = m + d_2 + (1-\kappa)p, \\
& c_2 = \kappa y - d_2 \\
& d_2 \leq \phi p \cdots (\lambda)
\end{aligned}
$$

The FOCs are

$$
\begin{aligned}
u'(c_1) &= 1 + \lambda \\
u'(c_1)p &= y
\end{aligned}
$$

In equilibrium, since the asset is held only by bankers, $\kappa = 1$ and $C_1 = M + D_2$, where the capital letters denote the aggregate level of variables. There are two states in period 1. Define c^* such that $u'(c^*) = 1$ and $\hat{M}$ such that $\hat{M} = c^* - \phi$. Then if $M \geq \hat{M}$, the economy is in the unconstrained state and $c^1 = c^*, d_2 = c^* - m, p = 1$; if $M < \hat{M}$, the economy is in the constrained state and $c_1 = m + \phi \frac{y}{u'(c_1)}$, $p = \frac{y}{u'(c_1)} \equiv p(M)$. Therefore,

$$V(m; M) = \begin{cases} u(c^*) + y + m - c^* & \text{if } M \geq \hat{M} \\ u\left(m + \phi p(M)\right) + y - \phi p(M) & \text{if } M < \hat{M} \end{cases}$$

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